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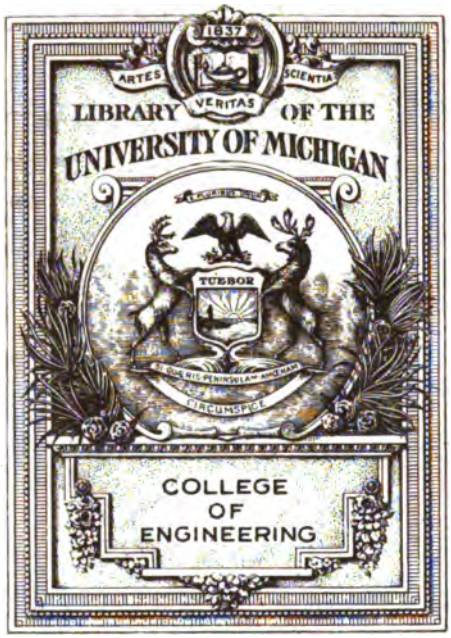
SINGLE-PHASE ELECTRIC RAILWAYS

EDWIN AUSTIN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SINGLE-PHASE ELECTRIC RAILWAYS

SINGLE-PHASE ELECTRIC RAILWAYS

BY

EDWIN AUSTIN

(On the Editorial Staff of "The Engineer")

NEW YORK

D. VAN NOSTRAND COMPANY

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PREFACE

THE following pages are devoted to descriptions of complete railways and portions of main line railways electrified on the single-phase system. Most of the chapters appeared originally in the columns of *The Engineer*, and I am indebted to the Editor of that journal for permission to embody them in this book. In England there are but two examples of single-phase operation, one on the Midland Railway, the other on the London, Brighton and South Coast Railway; but on the Continent the system has gained great popularity. Indeed, progress has been so rapid that this book has become much larger than it was intended to be at the outset. Even now it does not cover the entire field, but it describes some of the most important undertakings and refers to various schemes in the constructional stage. Its primary objects are to show what has been done abroad and to put before engineers and others interested in railway electrification details of overhead equipments, locomotives, motor coaches, etc., used on English, Continental and American single-phase lines.

Whilst the book was in preparation alterations and additions to existing equipments were constantly being made, and at the time of going to press a so-called "split-phase system" is being developed in America. Single-phase current is collected from the overhead wire; it is then converted into polyphase current and supplied to polyphase driving motors. As far back as 1891 Mr. Ward Leonard patented a similar scheme. It was proposed to feed a synchronous motor with single-phase current taken from the overhead wire; the motor was to drive a dynamo, this in turn supplying direct current to a driving motor. Other systems designed to avoid the use of single-phase commutator motors have since been devised, but they have not gained prominence. Most Continental firms are entirely satisfied with the single-phase motors they have developed; in America, on the other hand, there is every appearance of the "split-phase" system making headway.

The publication of this book has already been delayed considerably by endeavouring to make it cover everything. As soon as a new section was added something else called for another, until at last it became evident that it was time to stop. The book, therefore, goes to press without any reference, beyond that given here, to this new system which is attracting so much attention in America. Nor has much attention been paid to single-phase commutator motors, for those machines have been dealt with by many electrical writers.

I have received material assistance from various manufacturing firms, all of which are referred to in the text. To Mr. Philip Dawson, M.Inst.C.E., I am greatly indebted for help in describing the work carried out under his direction on the Brighton line.

E. A.

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CHAPTER I

THE SINGLE-PHASE SYSTEM

MANY engineers who have made a study of railway electrification have arrived at the conclusion that the single-phase system is very suitable for long-distance main line working, because it is possible to use 6,000, 10,000 or even 20,000 volts on the track. It is a common belief, however, that it is wrong to employ it on the interurban and suburban sections of main lines, and some authorities seem to contend that the proper thing to do is to put down a direct-current system for these short sections and to use alternating current for long journeys.

One of the most common objections to single-phase railways seems to be that the cost per mile of the overhead line is much more than that of the third-rail equipment, and it is believed to be far more expensive to maintain. A well-known electrical engineer has stated that a good and properly insulated overhead equipment for single-phase working costs nearly five times as much per mile of line as a third-rail equipment, and that its maintenance cost is also about six times greater than that of the third-rail. Assuming for the moment there is some truth in the statement, we have to remember that the direct-current system involves the use of rotary converter sub-stations. But the figures quoted above are much in excess of those obtained in practice. Very definite information with respect to these points is given in a letter written by Dr. H. Alexander to *The Times* in May, 1912. It seems from this letter that the cost of the overhead line for the Blankenese-Ohlsdorf City and Suburban Railway, constructed in 1908, was £1,250 per mile of single track, and that for more recent lines of the Prussian State Railways the cost has been considerably reduced by the employment of 100 m. spans, the price per mile now being about £800, including poles and erection, as against £1,000 to £1,200 for one mile of under-running third-rail equipment as used on main lines.

Moreover, the statement that the maintenance cost of the overhead equipment is about six times greater than that of the third-rail does not appear to apply to the existing Blankenese-Ohlsdorf line. Dr. Alexander also says that the operating costs of the City and Suburban Railway, Blankenese-Ohlsdorf, are practically the same as those of the Central London line, and lower than those of the West Jersey and Seashore line. As Dr. Alexander fully recognises, it is difficult to make a satisfactory comparison of the working expenses of any two railways, owing to the difference of conditions—such, for example, as profile of road, weight and nature of service of the trains, distance between stops, price of coal, and so forth. Nevertheless, the figures which the writer has provided are instructive, and it is to be hoped that similar particulars relating to single-phase working in this country will shortly be available.

In the light of results obtained in America, it appears undesirable that cars should be equipped with combined single-phase and direct-current gear to enable them to work on 600-volt lines within the suburban area. Such practice involves appreciable complications and necessitates the use of two distinct systems of generation or the employment of motor generators for the supply of direct current. It seems quite reasonable to assume that even if the single-phase system were proved

to be slightly less efficient than the direct-current system for working suburban services, it would be advisable to adopt it on suburban sections of main lines where there is a possibility of the electrified system being extended over long distances.

There is not the least doubt that certain changes which have been made in America from single-phase to direct-current have caused people in this country to have doubts as to the reliability and economy of single-phase working, particularly for suburban lines. There were various reasons for these changes, one being that the cars on some lines had to be fitted with combined single-phase and direct-current equipment, to enable them to pass on to the 600-volt street railway lines, with the result that considerable complications were introduced. Furthermore, some of the lines were electrified in the early stages of single-phase development, and the excessive maintenance charges were brought about by errors in design and faults that have now been eliminated. On the so-called high-tension direct-current lines the pressure employed is usually 1,500 volts, and two motors are connected in series. The maximum pressure that has been used on a commercial direct-current railway is somewhere in the neighbourhood of 3,000 volts, whereas in the case of the single-phase system a pressure of over 15,000 volts has been reached. Incidentally it may be mentioned that the advocates of high-tension continuous-current are finding that they require overhead wires, so that no more need be said about the excessive cost of the single-phase equipment.

Some years ago the Oerlikon Company succeeded in turning out a perfectly successful 2,000-volt direct-current traction motor, but, notwithstanding, the company discarded the high-tension direct-current scheme in favour of single-phase alternating current. This firm has come to the conclusion that even on short lengths of line, such as those constituting the suburban section of main line railways, the rotary converter sub-stations along the track represent such a great increase in the capital outlay and decrease in the over-all efficiency that the slightly higher costs associated with other parts of the single-phase system are not worth considering. Moreover, this firm has discovered—and the same report is issued by the American Westinghouse Company—that traction motors constructed for 15-cycle circuits are practically no heavier than those built for 1,500-volt direct-current railways. It is true that the alternating-current system is liable to give rise to trouble by reason of its effect on telephones, but in a paper read some little time ago in Switzerland, Dr. Hans Behn Eschenburg has shown how all such troubles may be avoided. As regards the question of power factor, excellent results are obtained with modern single-phase railway motors, and there does not appear to be room for much adverse criticism in this direction.

Before the single-phase railway motor was developed, a great deal of discussion took place with respect to the relative merits of direct-current and three-phase working, and it will be remembered that this was a question that gave rise to much argument at the time of the electrification of the District Railway. The three-phase system appears fairly good for certain conditions, but it does not seem to be applicable to many cases of railway electrification in this country. One of the principal objections to it is that it necessitates the employment of two overhead wires over each track and the use of two independent current collectors. At complicated portions of the track the employment of two overhead wires sometimes presents great difficulties. Furthermore, as there is a considerable difference of potential between these conductors, it is not at all easy to construct overhead equipment for such high voltages as are now employed with single-phase systems. On the other hand, the induction motor, which is the type of machine used on these

three-phase railways, is a remarkably simple and robust machine, and possesses the property of regenerating and returning current to the line without involving complications. When the rotor of an induction motor is revolved at a speed exceeding that of the magnetic field produced by the stator the machine becomes a generator and returns current to the line.

Thus on railways possessing steep gradients the motors send current back into the line when the train is on down gradients, and the output of the power station can be decreased in consequence. The speed characteristics of an induction motor, however, are similar to those of a shunt motor, and the machine tends to run at the same speed at all loads. Even if the wheels of a three-phase locomotive slip, the speed remains practically constant. The characteristics of the series motor are usually preferable for railway work, since the speed adjusts itself constantly and automatically to the different conditions. The regenerating property of the three-phase motor has proved a great advantage in Italy notwithstanding that resistances are used partly to limit the regenerated current. Single-phase locomotives can now be made to regenerate on down gradients, but it cannot be denied that this rather complicates the electrical equipment.

To obtain better conditions as regards speed regulation power factor, etc., it has been proposed to use three-phase commutator motors—a type of machine that has recently gained favour on the Continent—but it is quite obvious that this would be the means of robbing the three-phase railway of its principal asset—the simple induction motor. Before the single-phase commutator motor reached its present stage of perfection it was quite easy to understand why there was a tendency to adopt the three-phase system where the conditions were not favourable for the use of continuous current. But now that the single-phase system is well out of the experimental stage, and a large number of railways electrified on these lines are at work, it appears that the field for three-phase electrification is very limited.

No doubt cases are still to be found where the scheme would show up to good advantage, but it is, nevertheless, a fact that in the great majority of instances the choice lies between single-phase and direct-current.

With a full knowledge of the characteristics of each system, and after having made a careful study of the line it is required to electrify, it should be possible to give clear and sound advice, and a great many of the arguments that are constantly occurring might be avoided. So far as generalisation is possible, it appears that the direct-current system should be confined to tramways and overhead and underground lines that are not in connection with main line systems, whilst single-phase working should be adopted whenever there is a possibility of running heavy electric trains long distances. The point to be remembered is that the single-phase system lends itself to unlimited extensions whilst the low-tension direct-current system does not.

CHAPTER II

THE LONDON, BRIGHTON AND SOUTH COAST RAILWAY

WHEN it was decided to electrify some of the suburban lines of the London, Brighton and South Coast Railway, the merits and demerits of the alternating and direct current systems were carefully considered, and it was not until the work carried out in Europe and in the United States had been thoroughly investigated that the single-phase system was selected. The possibility of running electric trains to Brighton and to other places outside the suburban area was an item which had to be taken into account, and since the single-phase system is highly suitable for long distance working, it is difficult to understand why anyone should express doubts as to the advisability of employing it on this railway.

It was in 1903 that the directors of the company instructed Mr. Philip Dawson to report to them on the conversion of the suburban system. He was to consider whether electric working would enable the company more effectively to meet the severe competition which had been experienced from the electric tramways, and in the first instance, he was requested particularly to consider the advisability of electrifying the line between Victoria and London Bridge—a section of the railway which had suffered considerably since the introduction of electric traction on the London County Council's tramways. Mr. Dawson's report was forwarded to the directors in July, 1904, and after it had been examined, he was instructed to prepare specifications and to call for tenders for the electrification of a portion of the South London line between Peckham Rye and Battersea Park. The contract for the work was then awarded to the Allgemeine Elektricitäts Gesellschaft, Berl'n. It was afterwards decided to extend the electrified system to Victoria and London Bridge, and the contract for the work associated with this undertaking was signed on March 30th, 1906.

The first experimental electric train was run between Battersea Park and East Brixton on January 17th, 1909, and the whole of the electrified system between London Bridge and Victoria was opened for public service on December 1st of the same year. This section of the railway has been named " The South London Elevated Electric." During 1910 and the early part of 1911 extensions were made from Battersea Park through West Norwood and the Crystal Palace to Selhurst, and also from Peckham Rye to West Norwood. Furthermore, it has recently been announced that the directors have decided to equip for electric working the following portions of the line: (*a*) From London Bridge through South Bermondsey, New Cross, Brockley, Honor Oak Park, Forest Hill, Sydenham, Penge and Anerley to Norwood Junction; (*b*) the short connecting line between New Cross and Old Kent Road; (*c*) the short connecting line between the Sydenham-Penge line and the Crystal Palace; (*d*) from Norwood Junction through East Croydon and South Croydon, Purley Oaks and Purley to Coulsdon; (*e*) from Norwood Junction through West Croydon, Waddon and Wallington to Sutton; (*f*) from Tulse Hill through Streatham, Mitcham Junction, Hackbridge, Carshalton, and Sutton to Cheam; (*g*) the short connecting line from the East Croydon-Norwood Junction line to Selhurst; (*h*) the short connecting line from the West Croydon-Norwood Junction line to Selhurst; (*j*) from Selhurst through Thornton Heath, Norbury, and Streatham Common to Balham;

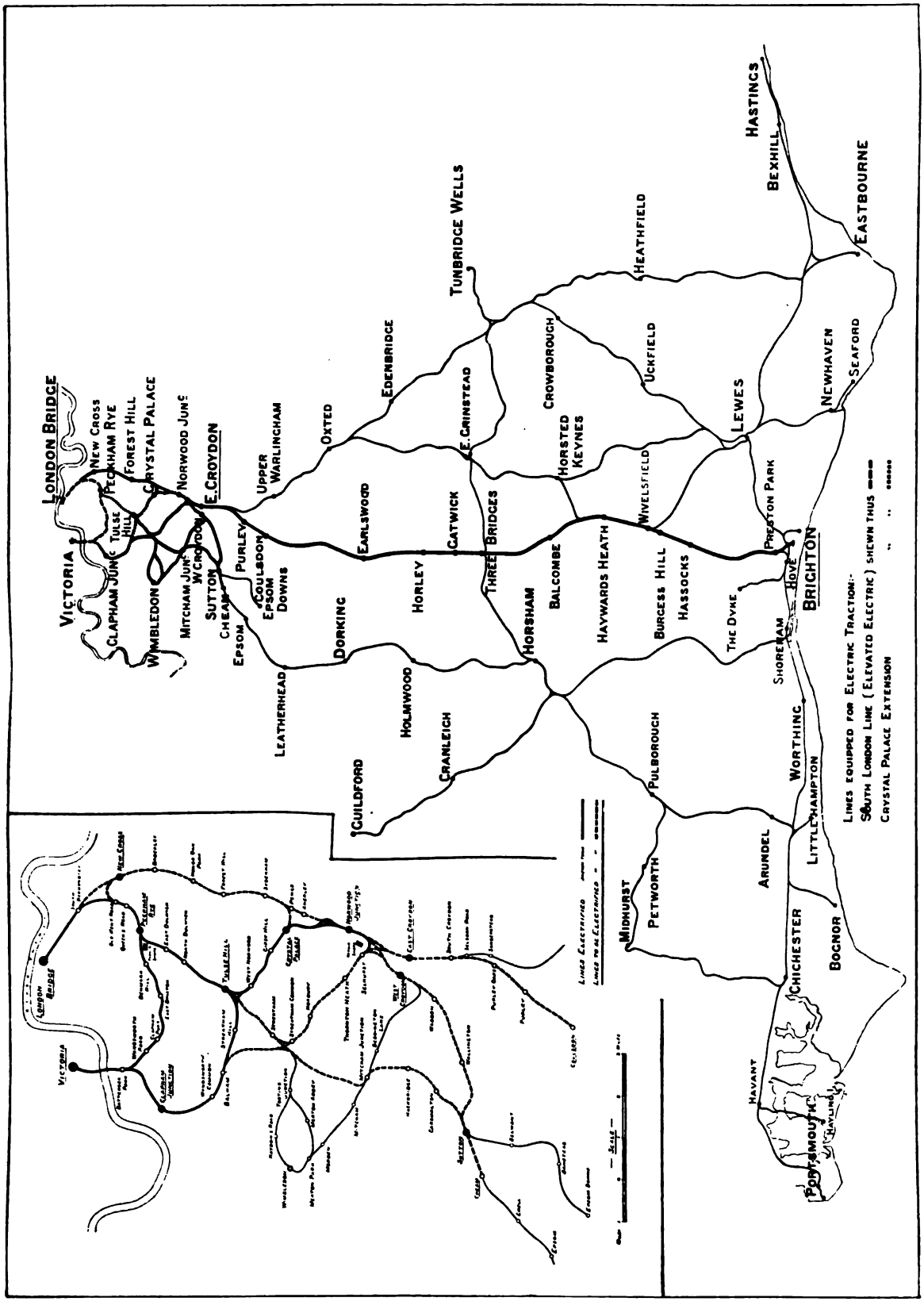


FIG. 1.—Map of the Brighton Railway.

(*k*) from Streatham to Streatham Common, and (*l*) the short connecting line between the Mitcham Junction-Streatham and the Streatham Common-Balham lines. Additional electrification of some of the lines in the vicinity of a few of the larger stations mentioned will also be necessitated. These proposals are set out in the small inset map (Fig. 1), in which the existing electric roads are shown in broad black lines, the roads which it is proposed to electrify in dotted lines, and other lines of the company in fine black lines. It will be observed that the only services in the immediate vicinity of London which are for the present, at any rate, not to be dealt with, are the Wimbledon loop, which includes the Tooting Junction, Haydon's Road, Wimbledon, Merton Park, and Merton Abbey stations, and the cross country line from West Croydon to Merton Park, which passes through Beddington Lane, Mitcham Junction, Mitcham and Morden. Farther out, the main Portsmouth line beyond Cheam, the Epsom Down branch, and the Sanderstead line are also for the present to remain as they are.

The lines now electrified represent some 70 miles of single track. The length which is now to be converted for electric operation is very nearly 150 miles of single track, including sidings, so that when the new scheme is completed the company will have some 220 miles of its lines electrically equipped. This, it is hardly necessary to say, constitutes by far the largest electrification scheme undertaken by a railway company in this country. The total length of the Brighton Company's system, including sidings, is given in " The Railway Year-Book for 1912 " as being 1,224 miles of single track. Two hundred and twenty miles represents rather more than one-sixth of the whole system.

This decision of the directors has not been unforeseen, for it is well known that success has followed the electrification of the sections already dealt with. Figures relative to the South London line—between Victoria and London Bridge by way of Battersea Park, Wandsworth Road, Clapham Road, East Brixton, Denmark Hill, Peckham Rye, Queen's Road, Old Kent Road, and South Bermondsey—which, as explained above, was the first portion of the line to be converted, are of interest. Before the London County Council's electric tramways came into competition with the line, some 8,000,000 passengers were carried on it per annum. By the year 1908, this number had decreased to something like 3,000,000, and, naturally enough, the receipts shrank with the diminution in passengers, and little or no reduction in working expenses was possible. Since the electrification, not only has the lost ground been recovered, but now some 10,000,000 passengers, or 2,000,000 in excess of the original figure, are carried each year. Practically no alteration in fares has been made, so that the increase in receipts has been very nearly proportional to the increase in passengers carried. Equally satisfactory results are being achieved with the other electrified lines, though on the Victoria-Crystal Palace line competition from tramways and motor omnibuses had been less severe. This was probably due to the greater distances between stations and to the direction taken not corresponding to a marked extent with that taken by main roads. The portion between Balham and West Norwood may be cited as an example of this. Nevertheless, in spite of there not being so much leeway to make up, the increase in the traffic during the first eighteen months was remarkable. Therefore, it is not surprising that the company has decided further to extend electric working. Indeed, it would not be a surprise to a great many were the directors eventually to make up their minds to convert the whole system for electric working. That, however, is looking somewhat far ahead.

The sections now to be electrified comprise four sets of lines between Balham and Croydon, and Sutton and Cheam, between Bricklayers' Arms, which is just north

of New Cross and Croydon, and between Croydon and Purley; three sets of lines between London Bridge and Bricklayers' Arms, the remaining portions having the ordinary two sets of lines. The present electrical rolling stock consists of fifty motor coaches. An additional 200 motor coaches will, in round figures, be required to operate the extensions.

It is noteworthy that the supply of electricity, which the company has hitherto purchased from the London Electric Supply Corporation, has proved so satisfactory, that it is intended to call upon this source for the additional current which will be required for the new lines. This will entail the installation at the Deptford generating station of additional plant of something like 40,000 or 50,000 kw., giving the station a total capacity, including that for its other power and lighting business, of about 80,000 h.p.

As is shown on the large map (Fig. 1), the Coulsdon station, to which electric trams are to run, is on the main Brighton line, and since it is nearly one-third of the way to Brighton, there is every reason to suppose that the directors will eventually decide to extend the electrified system to that popular seaside resort. It is also important to note that the whole of the service to Hastings and Eastbourne is worked over the same main line as far as Wivelsfield, which is ten miles from Brighton. These services together involve a total of almost sixty passenger trains a day in each direction, so that altogether it would appear that the electrification of the main line to Brighton is highly desirable. Further, the distance from London Bridge to Portsmouth *via* Brighton is only ten miles longer than the present route *via* Horsham and Arundel and the curves and gradients are less severe, so that if the main Brighton line is electrified the adoption of this alternative route is well within the range of possibility. When all these things are taken into account, it is easy to understand why Mr. Philip Dawson decided to employ the single-phase system.

On the line originally electrified from Victoria to London Bridge there are nine intermediate stations. It is 8·7 miles long, and the average distance between stations is 4,590 ft. The shortest distance between any two stations is between Old Kent Road and Queen's Road. The distance is 1,386 ft. It is seldom that a train runs in either direction without a stoppage due to signals. The running time allowed, according to the time-table, is 24 minutes, including stops.

Profiles of the South London lines and also of the later electrified portions of the railway are given in Fig. 2. They show that the conditions prevailing are by no means favourable for electrification, and having regard to the satisfactory results which have been obtained, it is evident that there cannot be very much wrong with the single-phase system. The curves which are indicated by the lines below the profiles are both sharp and numerous. Moreover, the gradients are long and severe, and there are rising gradients at each end of some of the stations. Many difficulties were encountered in electrifying the lines owing to the small clearances at bridges, etc., and a great deal of ingenuity has been brought to bear on the various problems which arose.

Two running lines have been equipped for electric working between Victoria and Peckham Rye, and three between the latter station and London Bridge. The second extension, which has now been completed some time, comprises a route length of $3\frac{1}{4}$ miles from Peckham Rye Junction to West Norwood, and just over 10 miles from Battersea Park to Selhurst *via* the Crystal Palace. Four tracks are equipped for electrical working between Victoria and Balham. On the remainder of the track as far as Selhurst two lines have been equipped for electrical working as well as the sidings at Clapham Junction, Streatham Hill and Crystal Palace stations, etc.

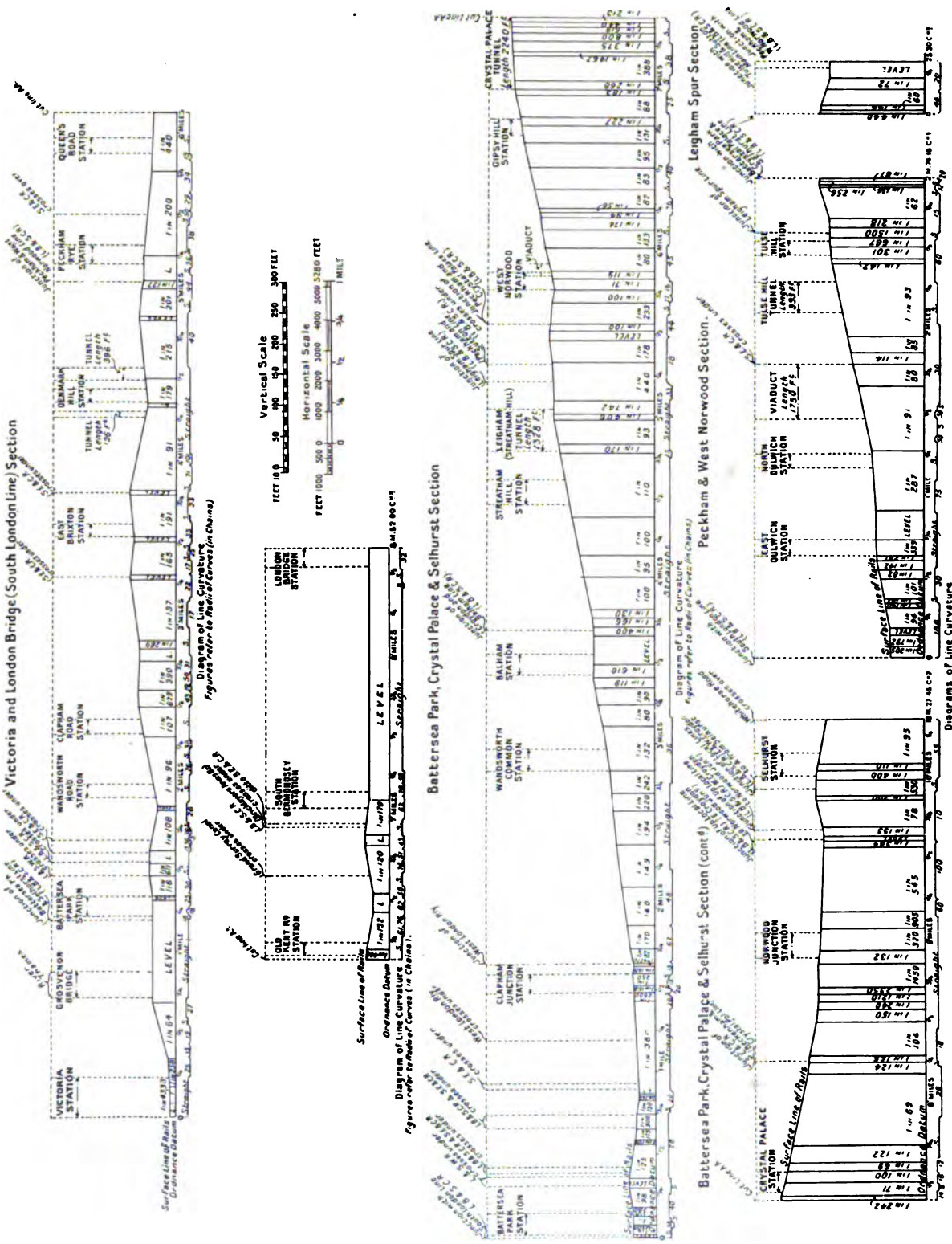


FIG. 2.—Profiles of Electrified Lines.

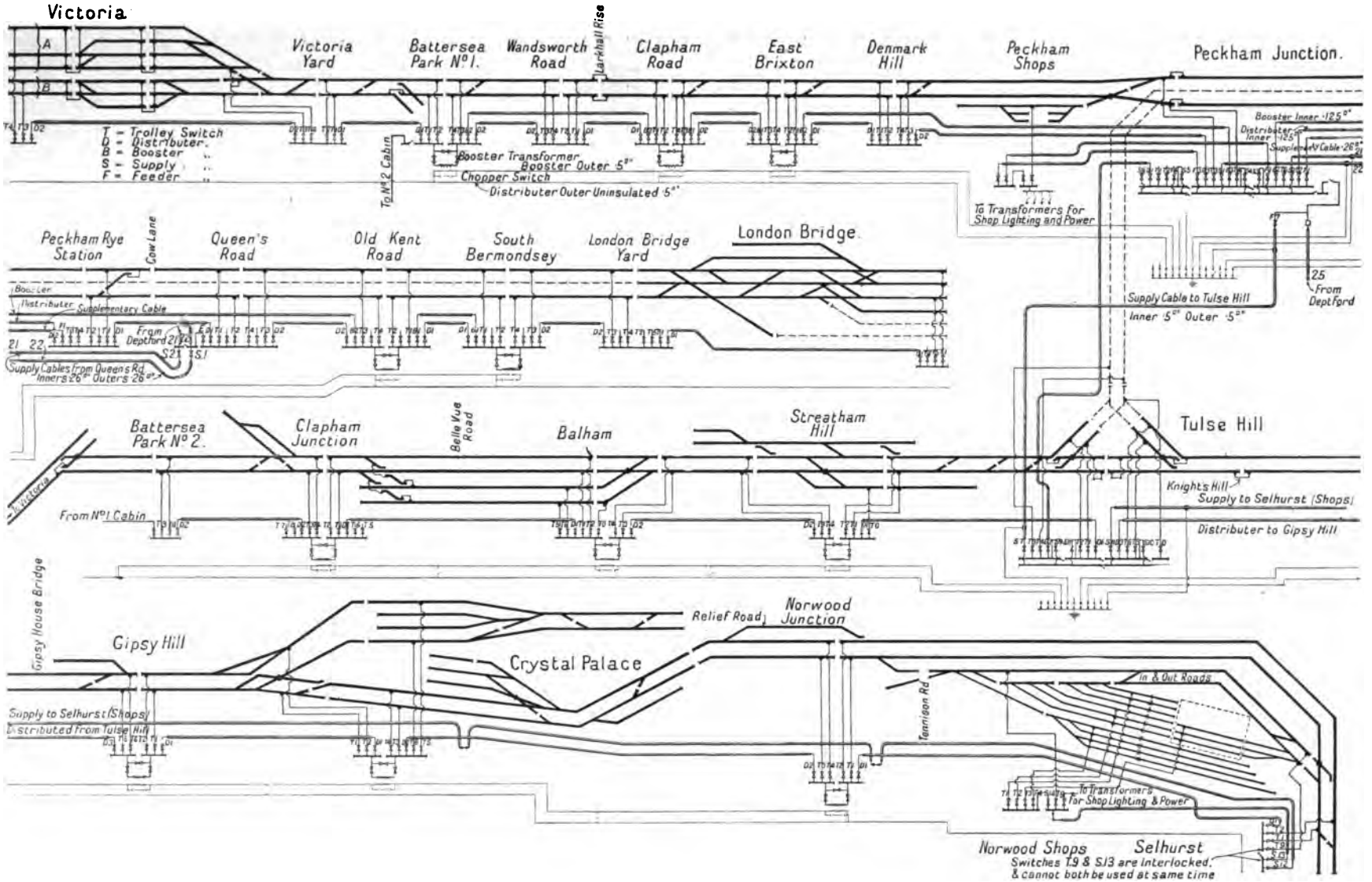


FIG. 3.—Distribution System.

The simplicity of the feeding and distributing system is shown very clearly by the diagram (Fig. 3) where the overhead central wires are represented by the thick lines, and the distributing cables and other cables by finer lines. The diagram is divided into four parts for the sake of convenience, but by referring to the map of the railway there should be no difficulty in understanding where the overhead conductors and cables are joined. The tracks represented by the dotted lines have now been electrified, and also other roads that are not shown at all, but the illustration gives a very good idea of the general wiring system. Before dealing with this diagram further, however, it should be stated that in view of the fact that the electrolytic effects of alternating current are less troublesome than those of direct currents, the Board of Trade fixed the maximum permissible drop in the return circuit at 20 volts instead of 7 volts as allowed for electric tramways. An entirely insulated return circuit was of course out of the question, and, consequently, this limit of 20 volts had to be kept well in view when designing the feeding and distributing system. The overhead system on the South London line is divided into sections as shown in the diagram. There is a complete section between stations. The up and down lines are entirely separate. But owing to the complicated nature of the work at Victoria and London Bridge, it was not possible to adhere to this practice at these points, consequently a zone was formed comprising all the complicated crossings. This is fed separately. The current is supplied to the South London lines from the power station at Deptford by means of two feeder cables. These terminate at the Queen's Road station switch cabin, where the current delivered to the railway is measured by a double set of meters. The feeders are then carried to the distributing room at Peckham Rye, as shown on the diagram. These feeders consist of two paper insulated lead-covered concentric cables, each conductor having a sectional area of ·26 sq. in. For the second extension another feeder was laid, this having ·5 sq. in. conductors, and for the extension between Peckham and Tulse Hill a further feeder was provided having ·26 sq. in. conductors, the latter two cables terminating in the Peckham Rye distributing room. There is also a feeder connecting the Peckham Rye distributing room with the distributing room at Tulse Hill, each conductor of which has a section of ·5 sq. in. So far these are all the feeders that exist, but there are naturally distributing cables which are connected in parallel with the overhead conductors, and with the aid of the switches in the switch cabins, the current can be cut off from any section without interrupting the supply on the remainder of the railway. There are also booster cables. Current is supplied to the railway at a pressure of 6,600 volts and at a periodicity of 25 cycles per second.

On the South London line the distributors and booster mains consist of two concentric cables, the booster cable being paper insulated and lead covered, whilst the distributor is a bitumen cable. The inner core in both cases has a section of ·125 sq. in., whilst the section of the outer core is ·5 sq. in. The distributing cable extends the whole length of the South London system. The outer conductor is laid over the bitumen protection, and is bonded to each rail length of the electrified lines. The rails are not bonded over the fish plates. The inner conductor, on the other hand, is led into each switch cabin and connected in parallel with the trolley wires, as shown in the diagram. On the other electrified sections of the line the booster cable has only one conductor, the inner conductor having been dispensed with. The inner conductor of the distributor, however, has a section of ·26 sq. in. as compared with ·125 in. on the South London line. The booster conductor therefore takes the form of a single low tension return conductor, having a section of ·5 sq. in., with paper insulation and a lead sheath. The booster transformers, which are intended to boost the return

circuit and to cause the current to return to the generating station by way of the cable, have a ratio of 1 to 1. It will be noticed (see Fig. 3) that the boosters are all connected in series both on the primary and secondary sides.

The modified form of booster cable used on the second extension system was employed with the objects of reducing the capital cost and of utilising the copper in the cables to better advantage. All the booster transformers are provided with short circuiting links on the low tension side, and on the high tension side there are two switches, one a double-pole switch, which serves to connect the booster in circuit, and the other a single-pole switch, which is used for short circuiting the high tension winding. The handles of these switches are interlocked, so that the boosting transformers are either connected in circuit as shown in the diagram, or cut out of circuit and the windings short circuited. Tests have been carried out with the object of determining the value of these boosting transformers, and it was discovered that little of the current returned through the rails or the outer conductor of the distributing cable. Nearly the whole of the current came back by way of the booster cable. When the boosters were cut out of circuit, however, about 84 per cent. of the current returned by way of the outer of the distributing cables to which the rails are bonded. From the diagram, Fig. 3, it will be seen that besides the cables already mentioned, a cable has been laid between the Peckham Rye distributing room and the Peckham repair shops, and between the Tulse Hill distributing room and the Norwood shops. In the case of the South London line, the bus bars in the switch cabins are connected to the overhead conductors by means of rubber insulated cables, whilst on the remainder of the electrified lines bare conductors are used. Four conductors emerge from most of the switch cabins, and they are connected to the overhead conductors on the up and down lines in the manner shown in the diagram. But at the No. 2 Battersea Park switch cabin there are only two conductors, because the section of the Victoria side of the cabin is fed from the Battersea Park No. 1 switch cabin, which is on the South London line. As a matter of fact, this section, with the exception of the short branch to Battersea Park No. 2 switch cabin, forms part of the South London line. There is an interconnecting cable between these two cabins as shown in the diagram.

The drawings of the switch cabins, Fig. 4, show that the switch gear is exceedingly simple. In those cabins where there are no boosting transformers, the equipment merely consists of a single bus bar and the switches, which are in circuit with the conductors which extend between the bus bars and the overhead lines. In those cabins which contain booster transformers, the bus bar is in two parts, and the primary windings of the transformer are connected between the inner ends. Consequently all the current passing through the bus bar also circulates through the primary of the transformer. The switches which are used for sectionalising the overhead lines are of the single-pole oil break type, and were constructed by the British Thomson-Houston Company. Those in circuit with the conductors connected to the overhead lines are fitted with automatic trip gear, but those controlling the distributing cable are hand operated. Isolating switches are provided between the oil switches and bus bars on the overhead conductor circuits. When the switches which sectionalise the overhead conductors are opened they connect the lines to earth. These switches are interlocked with the corresponding oil switches, and the latter cannot be closed whilst the boosting switches are open. A key which forms part of the interlocking gear can only be withdrawn when the isolating switches are open. To ensure that the lines are not energised whilst work is in progress, this key is taken charge of by the outside foreman. There can be no doubt about the lines being earthed, and they must remain earthed

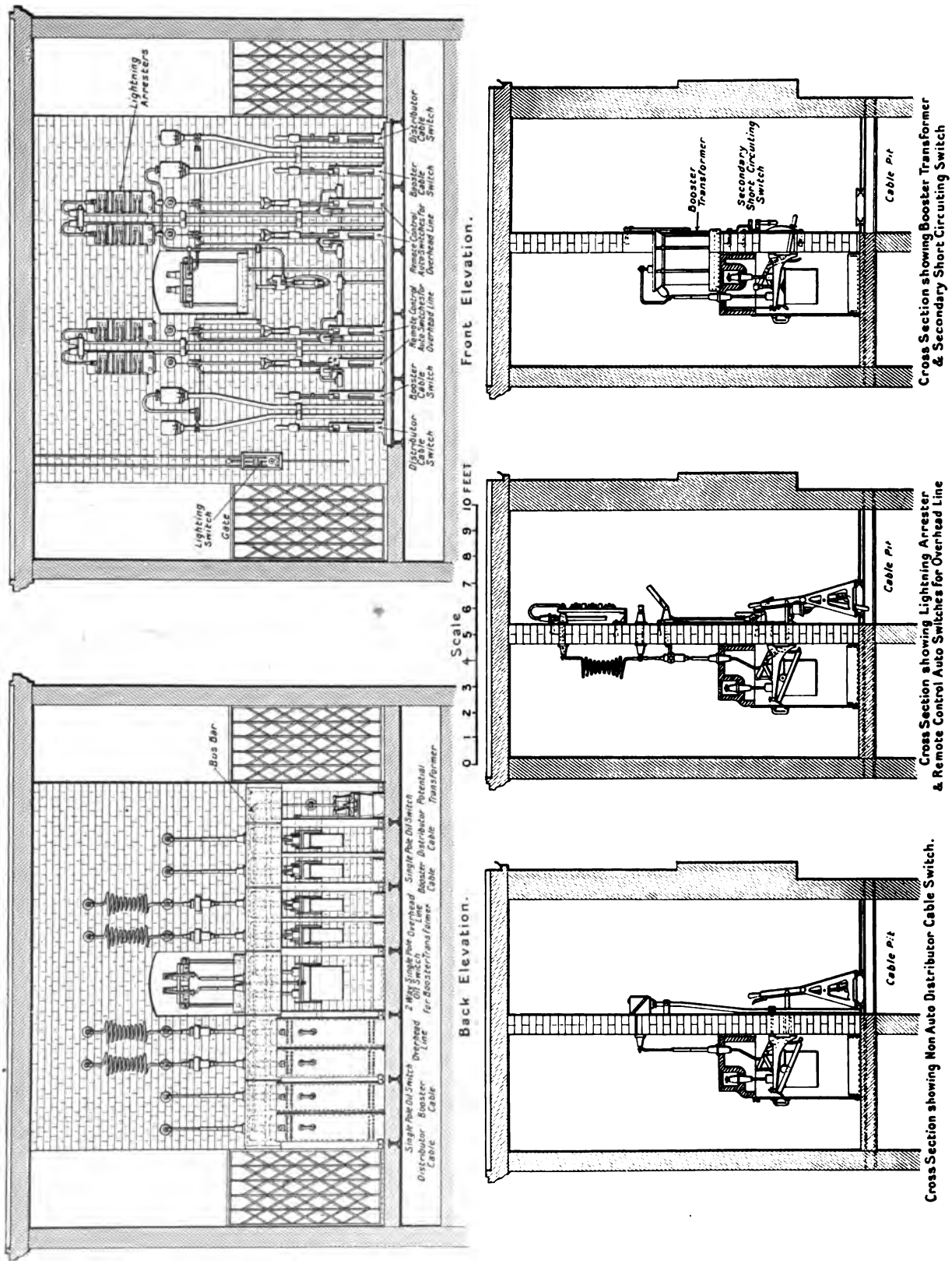


FIG. 4.—Switch Cabins.

until the key is replaced. The switching operations in the various cabins are carried out by the ordinary railway staff. If it becomes necessary to switch out any section of the overhead conductors, a telephone message is sent from one of the distributing rooms to the nearest signal box, and one of the men on duty then acts in accordance with the instructions he receives. Therefore, the electrical operations of the line are really controlled from the distributing rooms at Peckham Rye and Tulse Hill. Views of the front and back of the switchboard of the Peckham Rye cabin are given in Figs. 5 and 6 respectively.

The distributing rooms contain the instruments which meter the current supplied to the railway from the power station at Deptford. The arrangement of the bus bars is shown in the diagram, Fig. 7. Each distributing room contains two bus bars which are divided into sections, but they can be connected together by means of isolating links. Moreover, the sections of the upper bus bars are connected to the lower bar through automatic oil switches. Under normal conditions the isolating links in the lower bars are closed and those in the upper bar opened. The interconnecting oil switches are also closed. The current for the various branches of the railway is drawn from the sections of the upper bar, and in the event of a serious breakdown on any branch, the portion of the bus bar feeding the faulty branch is isolated. The links in the lower bus bar enable sections of the latter to be made dead for cleaning, etc.

The overhead construction on the Brighton railway is of the double catenary type. Two catenaries are suspended above the contact wire, which in turn is supported from them at intervals of about 10 ft. by dropper wires. The catenaries are not continuous. They can be adjusted at both ends by means of turn buckles, and the sag is so calculated that adjoining catenaries entirely balance one another, the result being that only the dead weight is supported by the structures. The latter consist of lattice or joist girders or cantilevers fixed at the top of steel towers (see drawings, Figs. 8, 9 and 10). The catenary wires are carried on insulators mounted on the girders or cantilevers, and where dropper wires are attached to the catenaries the latter are bridged by means of a horizontal cross tie, this tie and the droppers forming an equilateral triangle. There are twelve standard galvanised steel catenary wires each having a diameter of ·088 in. The droppers are looped over the catenaries and are attached to them by clips, this arrangement enabling the droppers to be removed without unfastening the catenaries. The jaws of the lower clip fit into the grooves in the copper conductor. The latter is ·5 in. in diameter, and has a minimum breaking stress of 22 tons per square inch. Droppers which are over 2 ft. 6 in. long are divided into two sections connected together by a link, so that there is a vertical play of 4 in. As the bow passes over portions of the line equipped in this manner, there is a slight lift in the links. Chains are used instead of linked droppers at the end stations where the bows are changed, because these are more flexible and more suitable for taking the jars which are produced when the bows are put into contact with the overhead wires. When designing the overhead equipment it was considered desirable to reduce the number of insulators to a minimum because these obviously constitute the weakest link. Very massive insulators have been employed, and a high factor of safety has so been secured both from a mechanical and electrical standpoint. Moreover, as the drawings show, a special type of pull off or push off is employed for staggering the overhead conductor, and for fixing its position so as to make it conform with the curves of the rails, these devices being suspended from the main insulators, which carry the catenaries. This construction is well illustrated in the drawing, Fig. 9, and it is scarcely necessary to enter into

FIG. 5.—Switch Cabin at Peckham Rye (Front View).

further details. Since these pull offs are supported from the same insulators that carry the catenaries, the insulation of the system is in no way weakened by these pull offs. The insulators are of the corrugated spool type, this form having been chosen after a

FIG. 6.—Switch Cabin at Peckham Rye (Back View).

series of tests had been carried out in London extending over a period of more than one year. Various designs of insulators were suspended in the open air and directly above the exhaust and smoke funnel of a steam engine. Tests were made under all kinds of

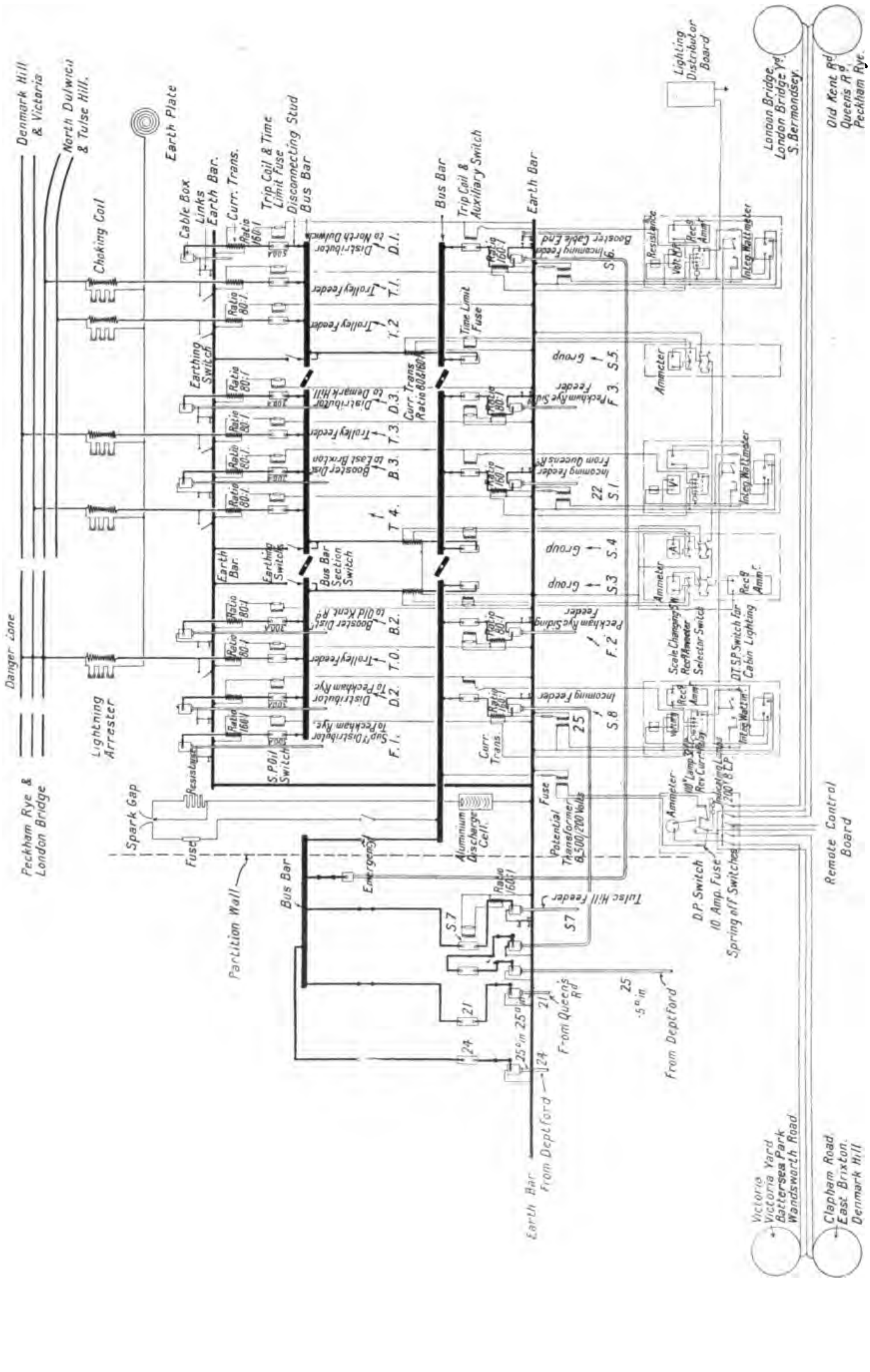


FIG. 7.—Connections for Peckham Junction Switch Cabin.

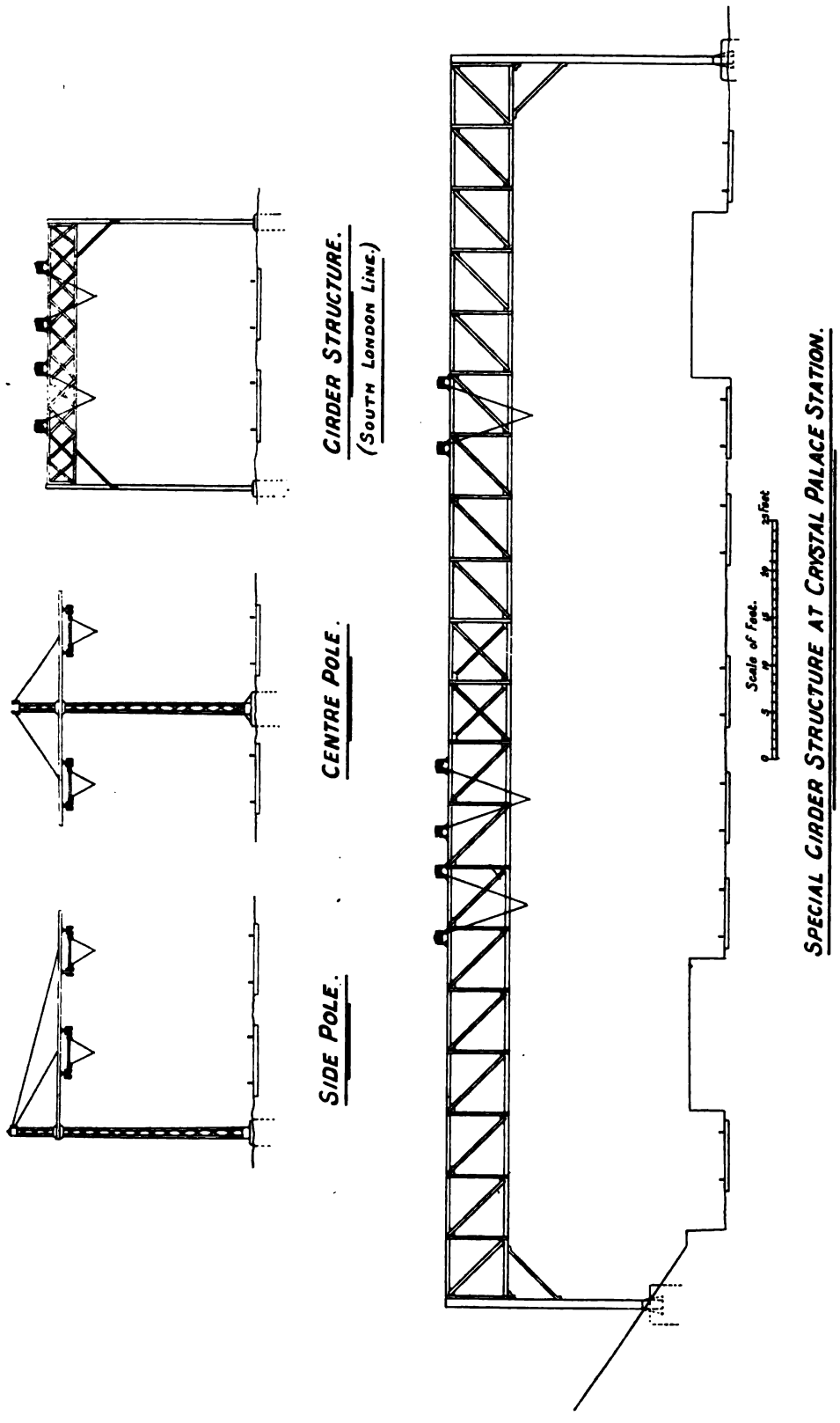


FIG. 8.—Various Types of Overhead Construction.

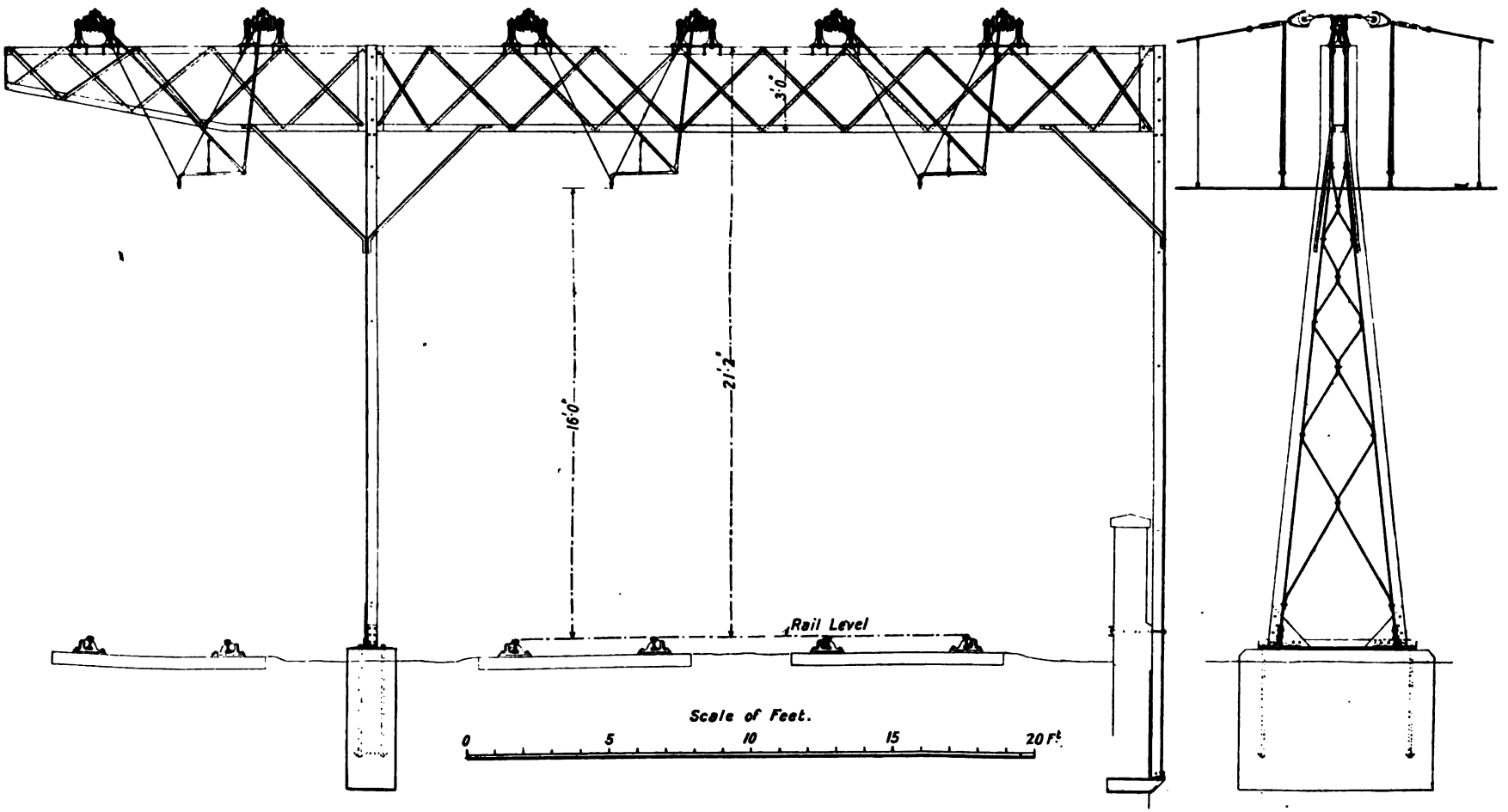
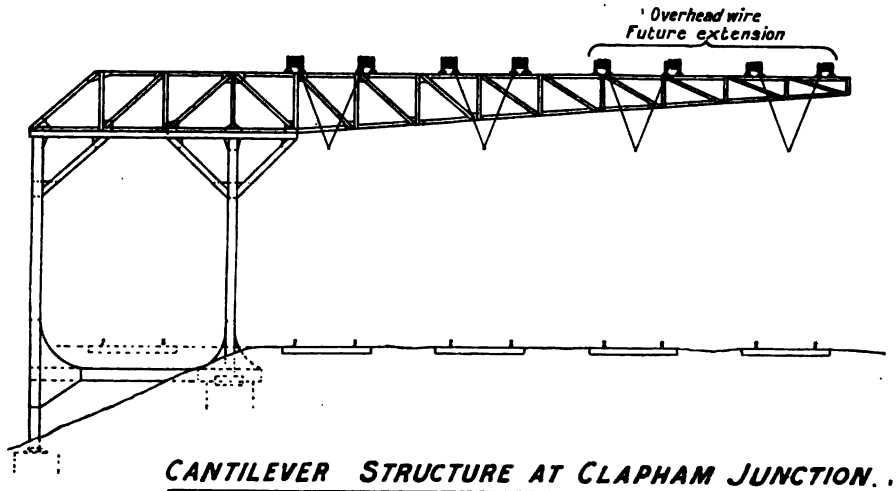
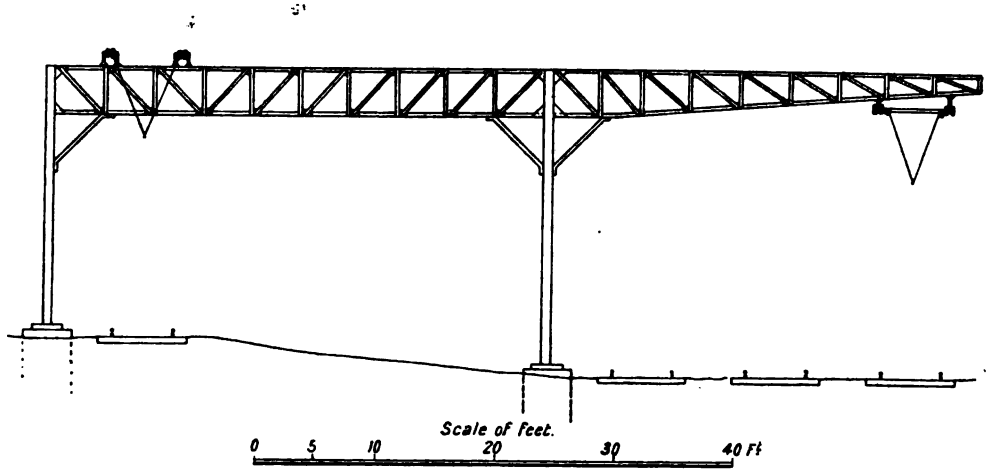


FIG. 9.—Girder Structure with Cantilever.

conditions as regards weather and so forth and with pressures up to 20,000 volts. Insulators were fixed over the funnel of a portable steam boiler, specially arranged to produce dense clouds of smoke or hot gases as desired, and the results went to show that the corrugated spool insulator was undoubtedly the most suitable under the particular conditions prevailing on the London, Brighton and South Coast Railway,



CANTILEVER STRUCTURE AT CLAPHAM JUNCTION.



CANTILEVER STRUCTURE AT SELHURST.

FIG. 10.—Cantilever Construction.

and also indicated that it is of the utmost importance that the insulators should be out of the way of the direct action of the hot gases emanating from the locomotive funnels. The insulation is double throughout the whole of the line. The construction of the towers and girders varies considerably according to the conditions prevailing on various parts of the railway. The illustrations, Figs. 8, 9, 10, show this. They are more or less self-explanatory; but attention may be directed to the extensive use of

pull offs in the case of the illustrations, Figs. 11 and 12, showing the Crystal Palace tunnel and to the construction used in one of the other tunnels (see Fig. 13). Here

FIG. 11.—Crystal Palace Tunnel.

insulators are mounted on steel joists covered with reinforced concrete, these joints being bolted to cast iron side brackets which are let into the walls of the tunnel.

At the Victoria and London Bridge stations porters have to light the gas lamps from the roofs of the carriages, and, because of this, the Board of Trade insisted on the conductors being 6 ft. 6 in. above the highest portion of any existing coach, thus

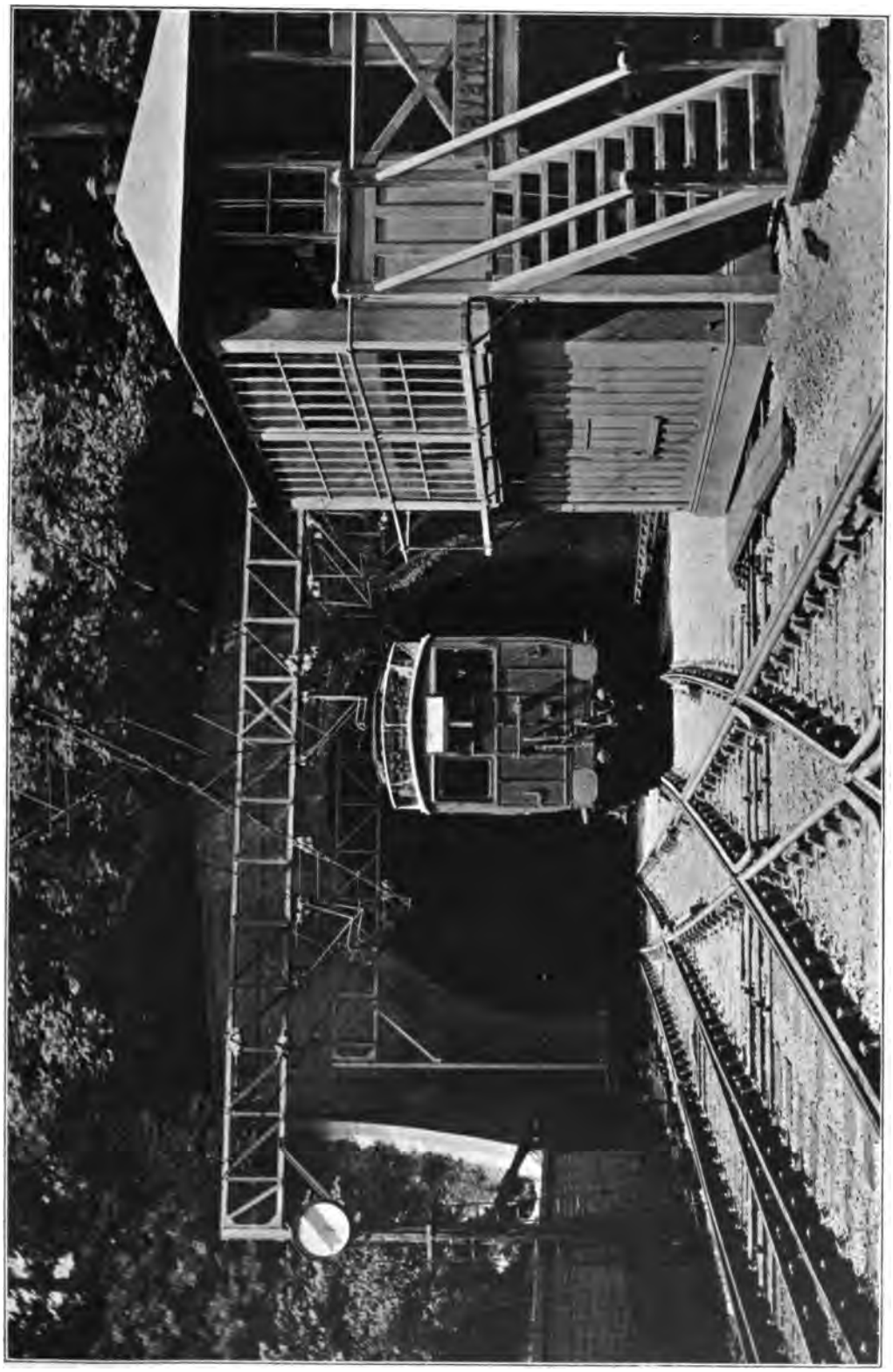


FIG. 12.—Train Leaving Crystal Palace Tunnel.

making the lowest position of any live wire 19 ft. 9 in. above the rail level. This not only applies to the wires in the stations just mentioned, but also to sidings on which unloading takes place. A good idea of the construction at Victoria Station can be gathered from Fig. 14. The average height of the conductor above the rail outside is 16 ft., the lowest wire being 13 ft. 9 in. above the rail level. The total variation in the height of the wire (inside and outside stations) is 6 ft.

In order to reduce to a minimum the dislocation of traffic in the event of a short circuit or earth on the overhead conductors, the lines are sub-divided into separate

FIG. 13.—Overhead Construction in Tunnel.

sections at each station on the South London line. In the first instance the section insulators consisted of self-contained neutral sections, but these have since been replaced on all the running roads by a more simple and more robust insulator, known as air-space insulators, the two conductors merely overlapping one another with a clear space between them, which is spanned by the bows in passing from one section to another. As is shown in Fig. 15, the wires are staggered, the object of course being to prevent grooves forming in the aluminium contact piece of the bows. The wires

FIG. 14.—Victoria Station.

are staggered 9 in. on either side of the centre line of the track. The width of the contact strips on the bows is 43¼ in. After the steel wires had been erected they were covered with two coats of hot tar, experiences with steel telegraph wires having shown that this practice greatly prolongs the life of the wires subjected to the bad influence of the London atmosphere.

Generally speaking, the supporting structures are 50 yards apart, but where circumstances demand it they are erected nearer to each other. Practically all the towers are composed of angle steel principals, with lattice bracing, and they are

FIG. 15.—Train at East Brixton Station.

secured to the foundation blocks by means of bolts. The cantilevers and overhead girders are made up of lattice structures throughout the South London line, but in the case of some of the extensions, where there are only short spaces over two tracks, simple joists have been used. Two types of bracing are employed for the lattice structures. In some instances the bracing is of the lattice pattern, and in others a simpler N pattern. The latter form of bracing has been used on the extensions because it was considered less liable to prevent the drivers seeing the signals.

The form of construction shown in Fig. 16 is of special interest. It is used at Pouparts Junction, on the Waterloo side of Clapham Junction, a part where the trains run close to the London and South Western Railway. It was not possible to

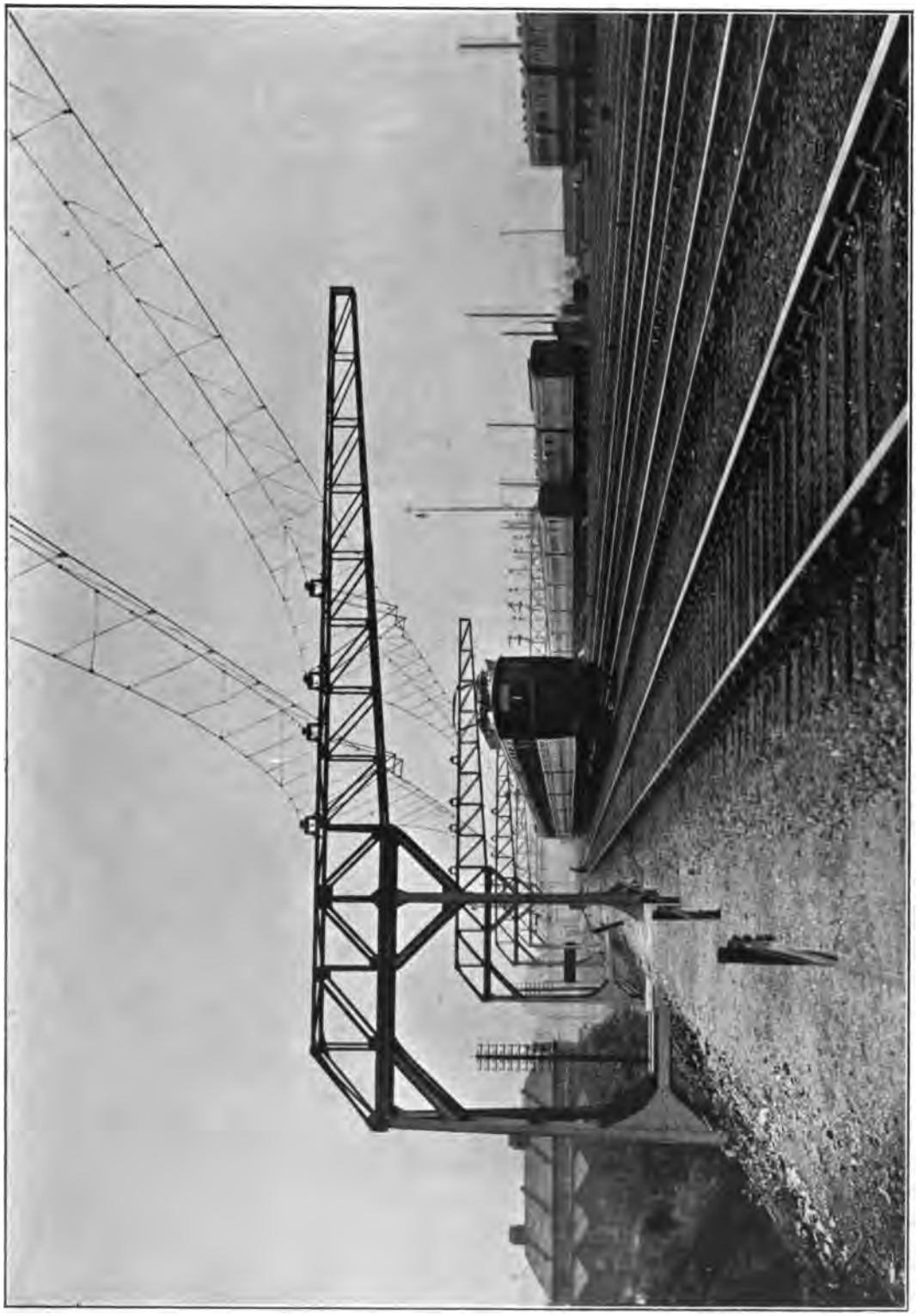


FIG. 16.—Cantilever Construction between Battersea and Clapham Junction.

erect a supporting tower for the inner end of the girders, and it was therefore necessary to use the cantilever form of construction shown. The overhanging cantilevers are long enough to support the contact wires for four tracks. Exceptionally deep foundations were needed for these structures.

Much might be written on the overhead construction of the Brighton Railway, but, since a great deal can be learnt from the drawings and other illustrations, it is scarcely necessary to enter into further details. Before leaving this portion of the work, however, it should be mentioned that, as an electrical clearance of at least 5 in. was necessary, under the three bridges over the tracks just outside Victoria

FIG. 17.—Overhead Construction on Bridge at Brixton Station.

station it was impossible to use live wires at those points. Consequently, a dead section has been provided under each of these bridges, which of course means that the trains have to coast when passing over these portions of the lines. Illustration, Fig. 17, shows the overhead construction on a bridge at Brixton ; Fig. 18, section insulators at Wandsworth Road ; Fig. 19, a cross-over road at Brixton station ; Fig. 20, the overhead construction under a footbridge ; and Fig. 21, the carriage sheds at Selhurst.

For the purpose of taking measurements under bridges and in tunnels, etc., a brake van was used, down the centre of one end of which a straight-edge was fixed vertically, as shown in Fig. 22. On the top of the straight-edge above the roof of the car

FIG. 18.—Section Insulators at Wandsworth Road.

FIG. 19.—Cross-over at East Brixton Station.

a cross piece was pivoted; this was fitted with a spirit level, and the under surface was also constructed to serve as a straight-edge. A drawing board was attached to the back of the brake van and a straight line was drawn through the centre. A pantograph was pivoted to the bottom part of the vertical straight-edge with a reduction of 4 to 1. When the vehicle arrived at a bridge or tunnel the pantograph was run under the straight-edge situated at the top of the van, the latter having previously been placed in position by means of the spirit level. The pantograph was then run along the surface of the structure whose height it was desired to measure. In this manner accurate drawings of every tunnel and bridge were obtained, giving the exact position of the track relative to the overhead structure under which the conductors

FIG. 20.—Overhead Construction under Footbridge.

had to be carried. Two men were seated on the roof of the van, as shown in Fig. 23, in order to take additional measurements where necessary.

The rolling stock differs considerably from that of other electrified lines in this country. The use of the end, or American, door commonly employed on other electric railways did not commend itself in the case of the Brighton line, because during the busy hours of the day practically all the passengers enter and leave the trains at the termini, and not at intermediate stations, as on many other electric railways, and without multiple side doors it would be impossible to fill and empty the carriages in the short interval during which the trains remain in the stations. Moreover, in order to reduce to a minimum the stopping time at intermediate as well as at terminal stations, it was considered desirable that the coaches should be designed so as to eliminate the

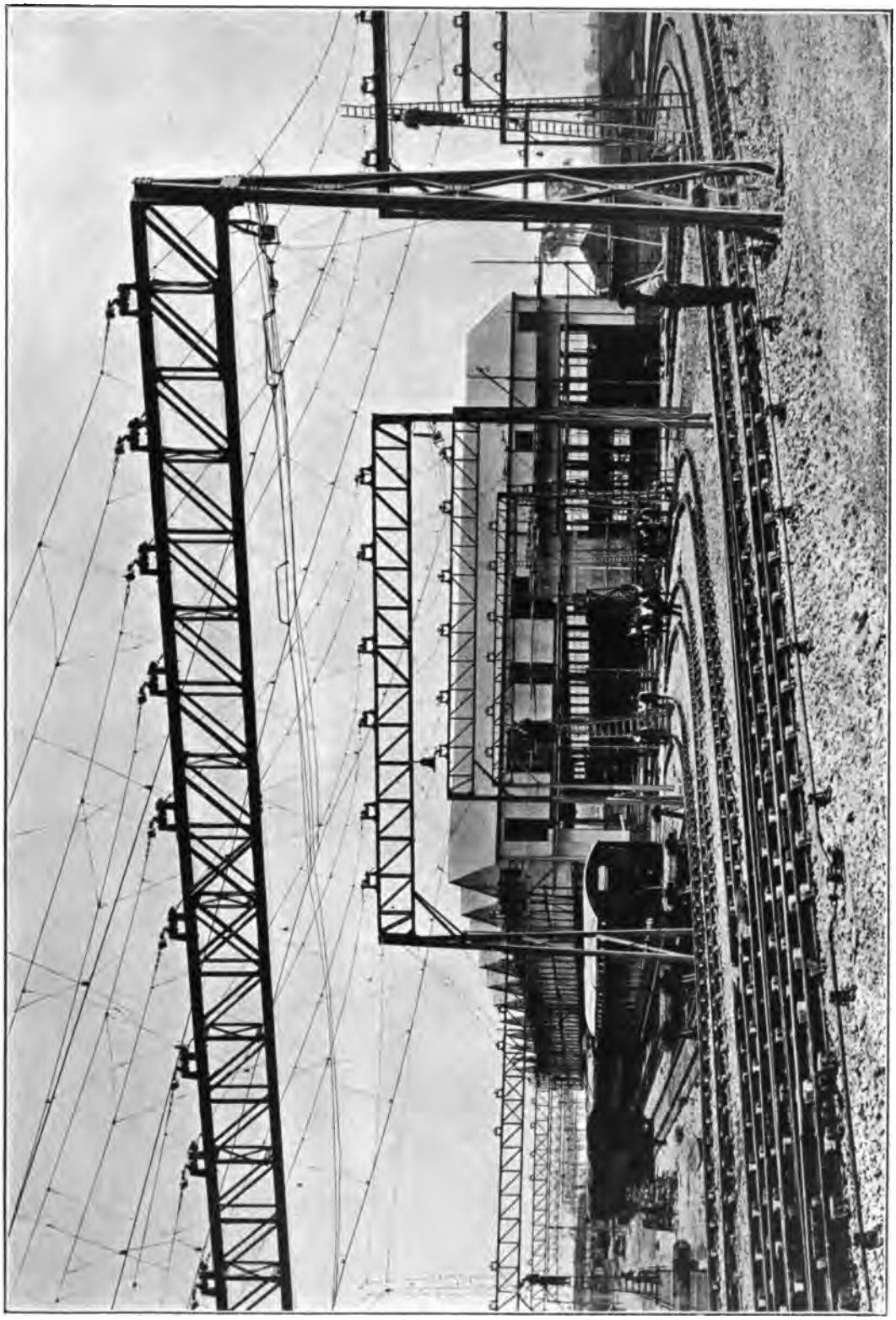


FIG. 21.—Carriage Sheds at Selhurst.

necessity for passengers having to walk or run along the platform in order to find a

FIG. 22.—Coach Equipped for taking Measurements.

vacant seat. With this object the coaches built for the South London line have been constructed with a side corridor, so that passengers entering at any door can afterwards walk along the corridor and find a seat after the train has started. The overall width of those originally designed for the South London line is 9 ft., which enables a passage way to be employed between the compartments without diminishing the seating capacity to any appreciable extent. These carry sixty-six third-class passengers, and trailer coaches of similar length fifty-six first-class passengers. There are no second-class compartments. The length of the coaches is 60 ft. In the case of the extensions, however, certain obstructions, notably in the Crystal Palace tunnel, prevented coaches of these dimensions being used, and it therefore became necessary to employ coaches without corridors, these being only 56 ft. long and 8 ft. wide. The third-class compartments of these coaches accommodate five passengers on a seat, and the first-class four passengers. Third-class motor coaches of this type accommodate seventy passengers, a composite first- and third- class trailer

FIG. 23.—Taking Measurements in Tunnel.

seventy-four passengers, twenty-four first-class, and fifty third-class. The first-class compartments are confined to the trailer coaches. Some old coaches, originally hauled by steam locomotives, have been remodelled and used as trailers on the Crystal Palace line. Originally the trains of the South London line were composed of units of three coaches, the first and last being motor coaches, each of the latter being equipped with four motors. In those days two motor coaches were necessary, because the largest motor then available only developed 115 h.p. on the one hour rating. Since then, however, more powerful motors have been built. The trains are now composed of units of two or four coaches, consisting of one motor coach and one trailer, or two motor coaches and two trailers, instead of units of three coaches as in the first instance, which arrangement was unsatisfactory. On the Crystal Palace lines the units consist of one motor and two trailers, forming six-coach trains. The motor coaches which have been built latterly are fitted with four 150-h.p. motors. No attempt can be made to enter into the mechanical details of the coaches. It must suffice to say that they are built of wood in accordance with the Brighton Company's usual practice. In order to ensure safety, and to prevent any part of the coaches becoming charged by reason of leakage from the current collectors and other live parts, the roofs and sides of the coaches are made of sheet aluminium, which is connected to the metal underframes, with the result that no part of the coach body can attain a pressure above earth potential.

All the motors used on the old and new types of coaches are of the Winter-Eichburg compensated repulsion type. They have four poles and six slots per pole. The armatures are similar to those used in direct-current motors, but four of the six brushes are short circuited, and the exciting current is fed in at the other two brushes. An elementary diagram of connections of one of the motors is shown in Fig. 24, but in this instance only four brushes are illustrated, two main brushes, which are short circuited, and two other brushes, which are connected to the exciting transformer. The short-circuited brushes are opposite the middle of the pole face, and the exciting brushes at a point between the poles. Compensating windings are provided on the faces of the poles. The motor connections are clearly shown in the elementary diagram, Fig. 24, which is self-explanatory, the order in which the contactors close being shown by the inset table. Fig. 25 gives a complete diagram of connections for a motor coach. The shafts of the motors are hollow for the purpose of ventilation, and air is drawn through the machine by a fan at the back end of the armature. Fig. 26 shows a section of one of the motors. A motor bogie is shown in Fig. 27.

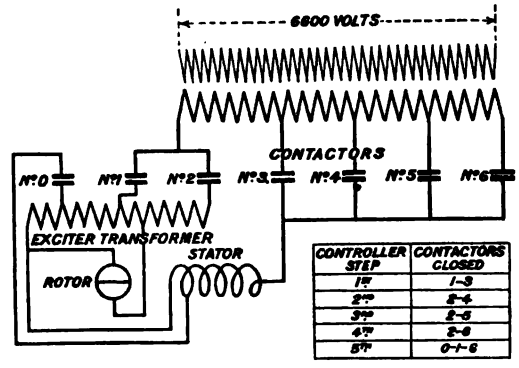


FIG. 24.—Motor Connections.

The gear ratio of the motors is 4·24 to 1. The synchronous speed of the armature is 750 revolutions per minute. A 220-kw. transformer is provided for each pair of motors. There are, therefore, two main transformers on each motor coach. Each pair of motors is also provided with an exciter transformer of the auto type. Current is supplied to the main transformers at a pressure of 6,600 volts, and the ratio of primary to secondary turns is such that the maximum pressure which can be obtained from the secondary is 750 volts. As the handle of the controller is turned from the first to the last position the pressure increases from 450 volts to 580, then to 640, and,

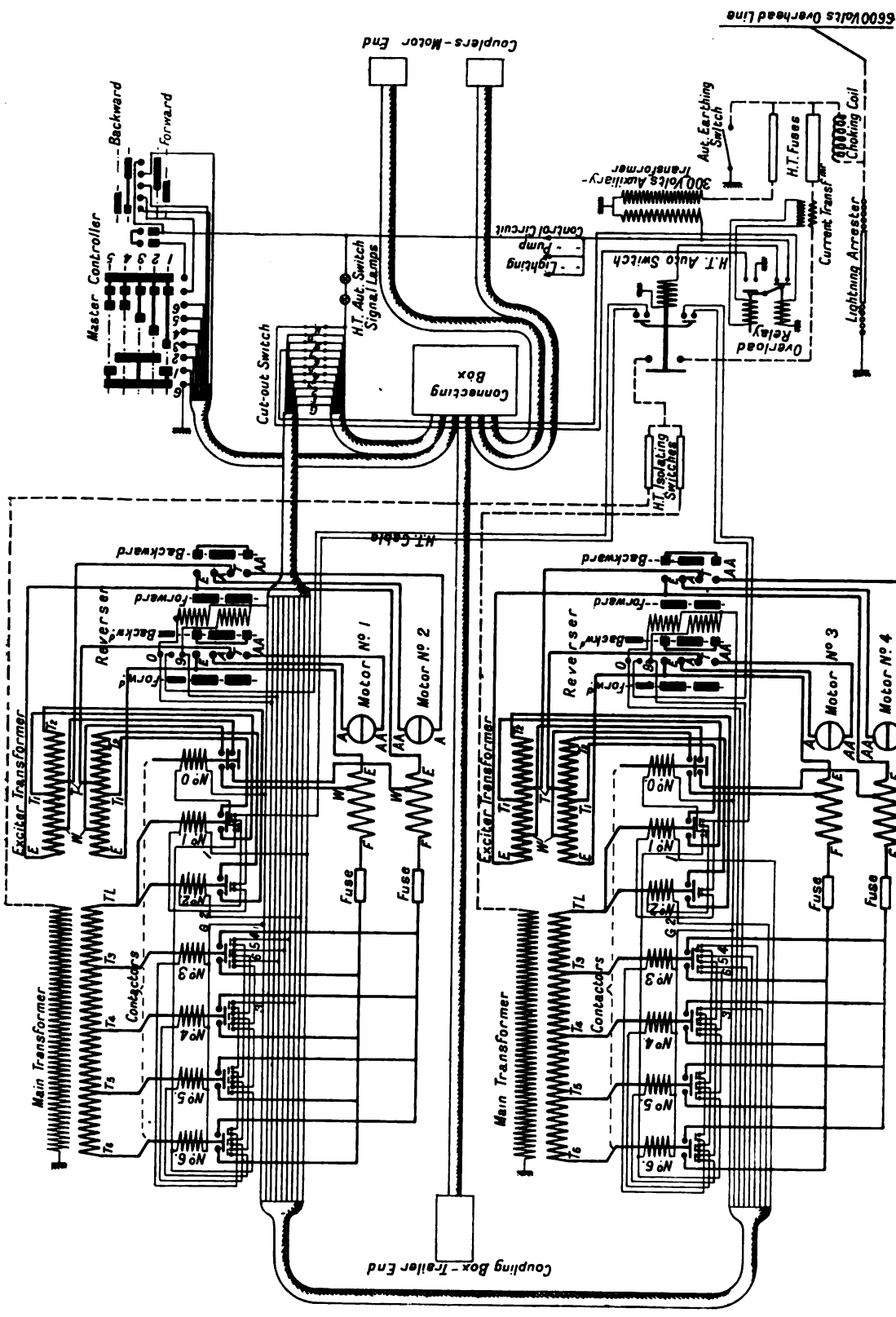


FIG. 25.—Motor Coach Connections.

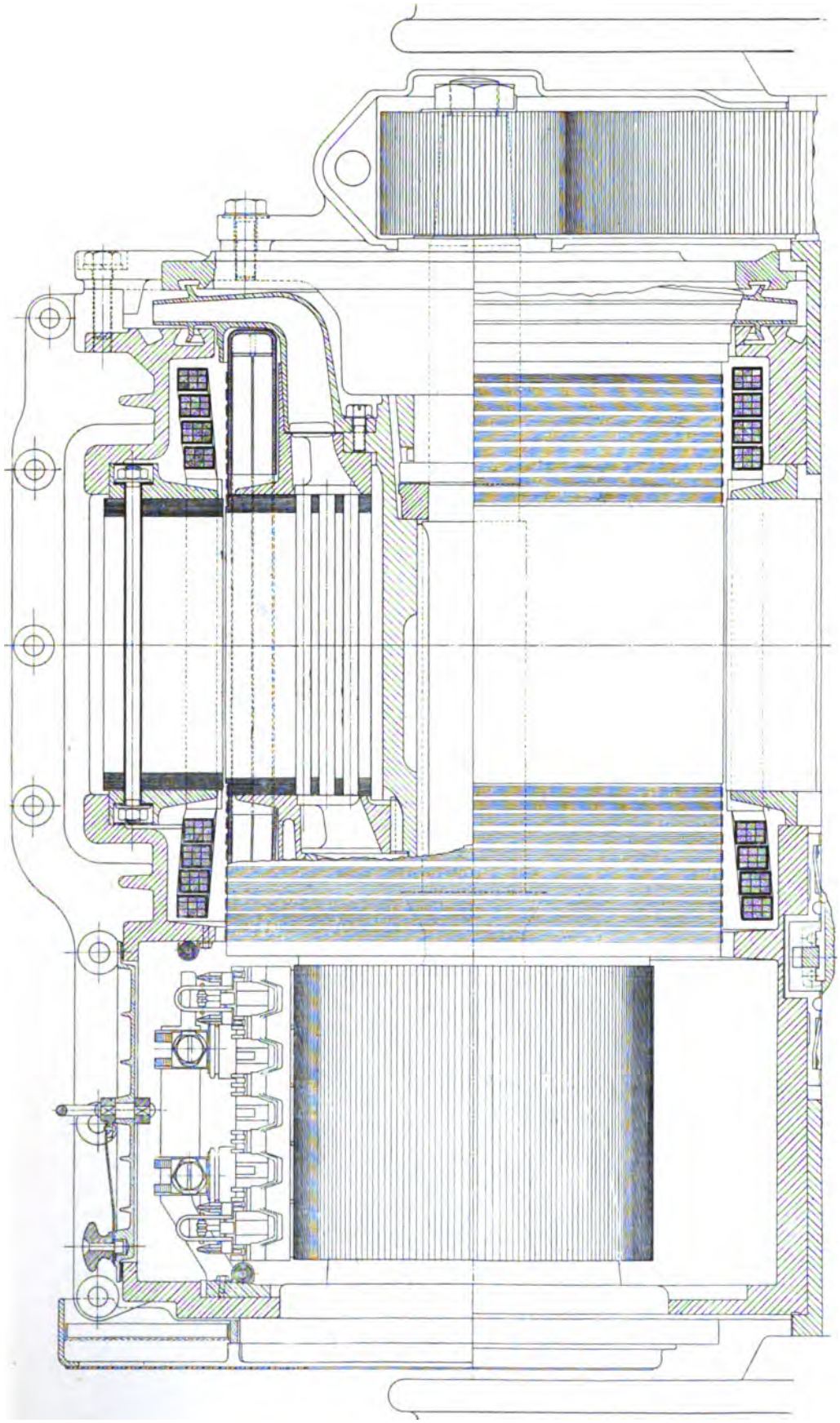


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FIG. 26.—Section of Motor.

finally, to 750 volts. In a similar manner the pressure of the small exciter transformer is changed by means of two contactors. An advantage attending the use of this type of motor is that a fairly high voltage can be applied to the terminals. The following table gives the voltages at the terminals of the main and exciting transformers corresponding to the five positions of the controller handle:—

Position of Controller Handle.	Secondary Pressure of Main Transformer.	Ratio of Exciter Transformer.
	Volts.	
1	450	78 : 104
2	580	104 : 104
3	640	104 : 104
4	750	104 : 104
5	750	78 : 104

Now let us examine the connections for a complete motor coach (Fig. 25). The high tension circuit conveys the current from the bow to the primaries of the main transformers and then to the rails. There are three paths which the current can take. The first is formed by the discharge side of the lightning arrester, and consists of a series of spark gaps and a carbon resistance connected to earth. The other two paths are the circuits for the main transformer and for a small auxiliary transformer for the control pump and lighting circuits. In the main power circuit there is a fuse, a current transformer, a main oil switch and high tension isolating switches. The latter are for the two main transformers. The third circuit is provided with a low-capacity high tension fuse, which protects the small auxiliary transformer, one end of the primary of which is connected to earth, like the ends of the primaries of the main transformers. It will be seen that the circuit from the bow to the auxiliary transformer is not interrupted when the main oil switch opens, this being a desirable condition on account of the fact that it is necessary that current should always be available for the control circuit and for lighting purposes. The control current is taken from the auxiliary transformers at a pressure of 300 volts, and, since one end of the winding of this transformer is earthed, it is evident that the pressure between the control wires and earth is 300 volts also. The 300 volt end of the auxiliary circuit has five branches. One supplies current to the hold-on bobbins of the high tension automatic oil switch, and, as will be seen from the diagram, this circuit can be interrupted by the overload relay. Therefore, when an excess current passes through the current transformer the oil switch is opened. It is also opened when the supply fails, and closed automatically when it is renewed. Moreover, the solenoid operated by the current transformer closes the second of the circuits connected to the 300-volt auxiliary transformer, and this has the effect of lighting the red signal lamps placed above the driver's hand. The pump circuit, which is the third circuit fed by the 300-volt auxiliary transformer, operates independently of the remainder of the circuits, its action being dependent on the air pressure in the train pipe. The lighting circuit is also independent of the others, but a connection from this circuit is used in conjunction with a special dead section switch, and by operating this it is possible to obtain current from the rear bow whenever the front bow is on a dead section of the overhead conductor. Finally, the other circuit to be considered is the main controlling circuit, which supplies current for working the contactors and the reversing switches throughout the whole train. It will be noticed that the master controller is divided into two

parts. The one operating the reversing switches is controlled by a small handle, which is removable, and the other, which operates the main contactors, is controlled by the main driving handle. The small bridging piece between the two parts of the controller is the " dead man's thumb," which must be depressed by the driver whilst the train is in motion, otherwise the power current is cut off and the train automatically brought to a standstill by the brakes. When the reversing handle has been placed in the desired position, the controller handle is turned from notch to notch, and the

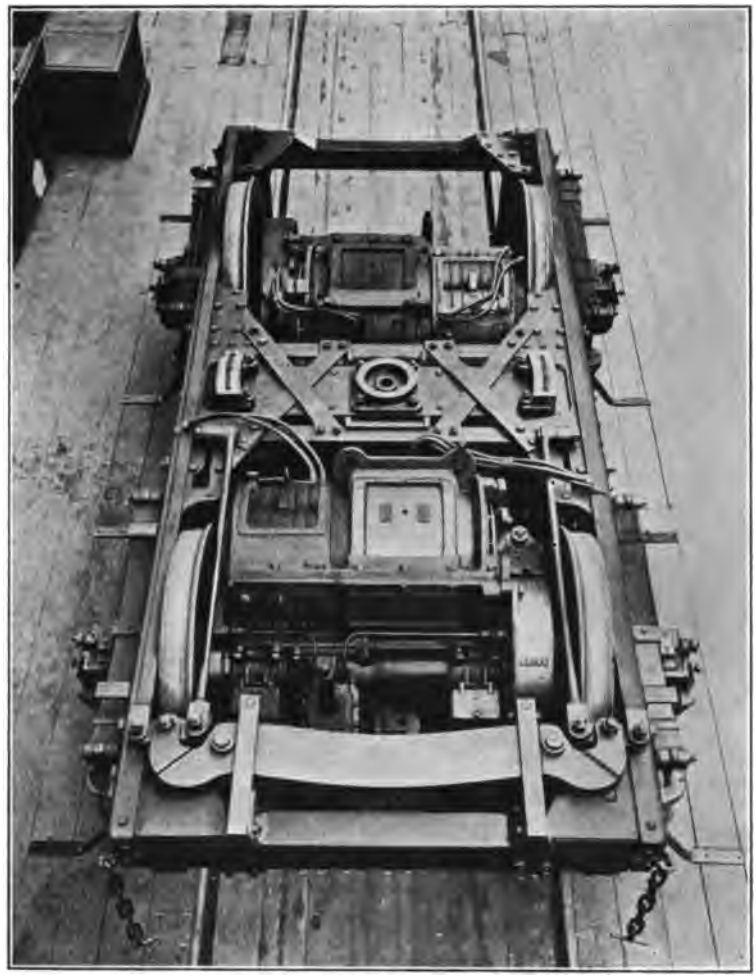


FIG. 27.—Motor Truck.

contactor solenoids are then energised in the proper order, thus making the necessary connections on the low tension side of the main transformer and also on the exciter transformers. It is impossible for the contactors to make a new connection to the motors without first opening the previous connection. Therefore, no portion of a transformer can be short circuited. Fig. 28 is a view of the underside of a motor coach with the truck removed, and shows one of the transformers and wiring.

Since the low tension power circuit is not earthed, a breakdown in the insulation on one side of the transformer, or on any of the low tension power cables, does not produce a short circuit. Every possible precaution has been taken to prevent anyone

coming into contact with the high tension equipment when it is alive, and in order to secure perfect safety, a high tension chamber is provided at the end of each motor coach, and the current is led into this chamber by a conductor passing through the roof. Each of these chambers contains the lightning arrester, main oil switch, two main fuses (one for power and the other for lighting), two isolating switches for the main transformers, an auxiliary transformer for lighting, pumping and control, a current transformer connected in the main circuit, and measuring instruments, including an integrating watt meter, voltmeter and ameter. Two arms are connected to the bow mechanism, so that the doors of the high tension chamber are always locked whilst the high tension gear is alive. Moreover, the act of opening the door releases the air from the pistons which operate the springs holding the bows in position.

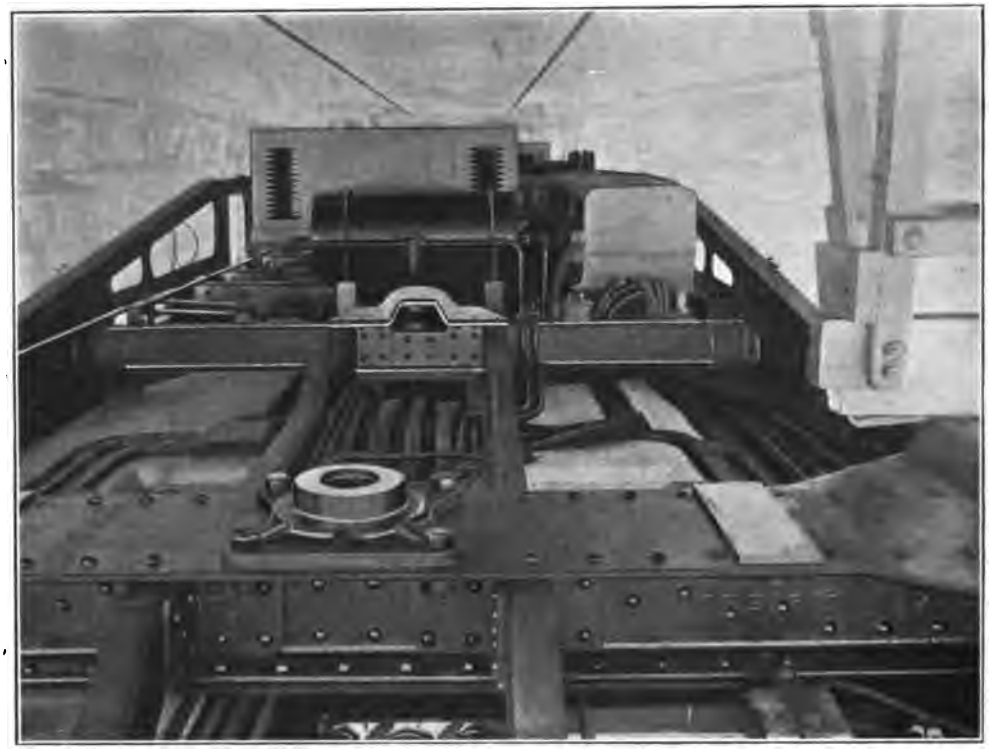


FIG. 28.—Underside of Motor Coach (Truck Removed).

As a further precaution, when the door is opened the apparatus is automatically earthed. There is a low tension cupboard on each motor coach which contains the switches for controlling the lighting circuits, also a switch controlling the operating circuit of the main oil switch, and the connecting box and cut out switch for the contactor circuits. A drawing of one of the motor man's compartments and high tension chambers is given in Fig. 29. The contactors have two operating coils, and the phases of the currents which pass through these are displaced, so as to produce an uninterrupted pull. One of these coils is directly connected across the 300-volt circuit, and the other is joined in series with a resistance which serves to produce the necessary phase displacement for the purpose already mentioned, and is connected to the 300- and 60- volt points of the auxiliary transformer. When the contactor circuit is broken, the 60-volt tapping remains connected to the contactor coils and produces a small current in the

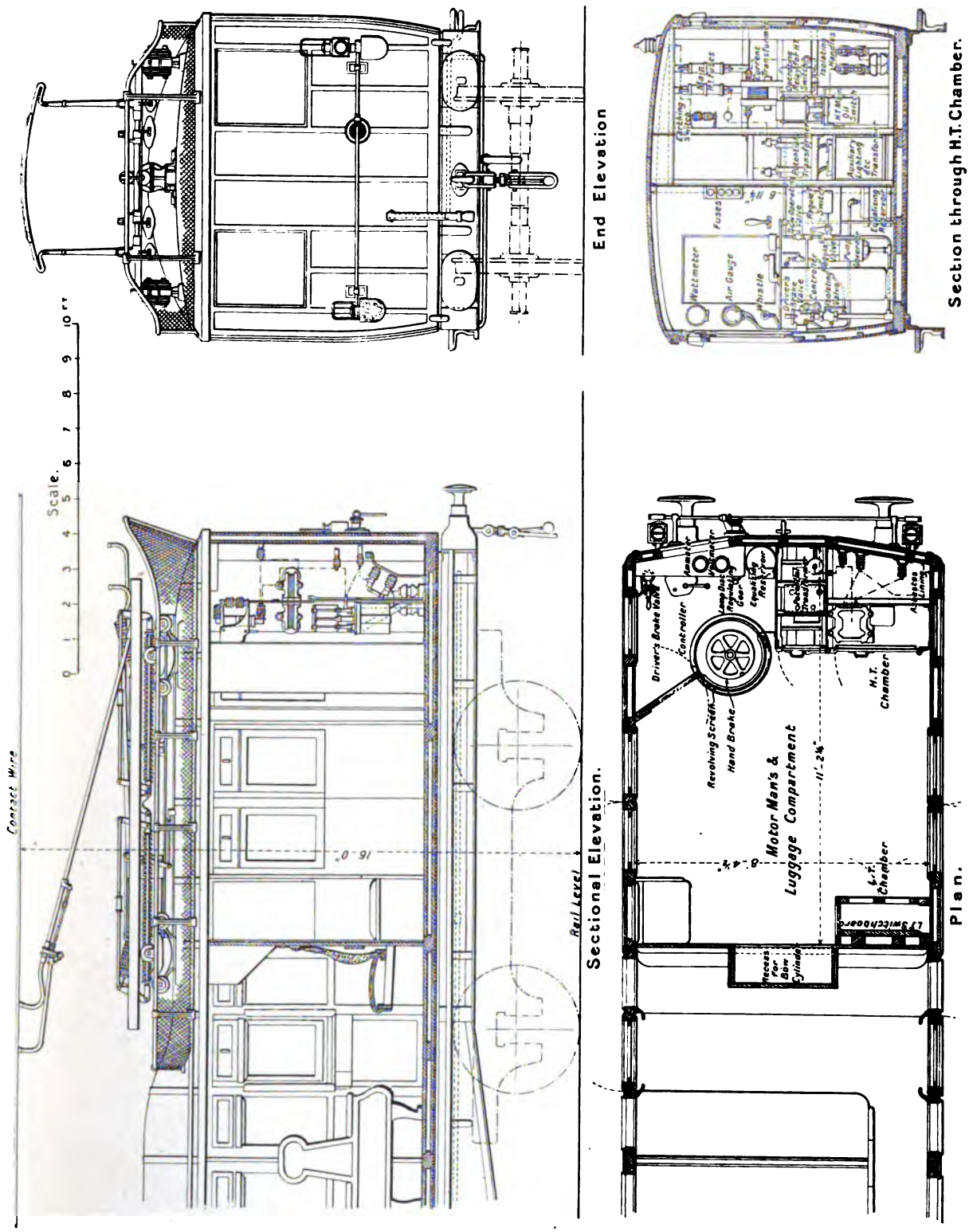


FIG. 29.—General Arrangement of Motor Man's Compartment and Driving Gear.

windings which flows in the opposite direction, in the split phase coil, to the direction in which the current flows under working conditions, that is to say, when the contactors are closed. The object of this is to ensure that the contactors open as the handle of the master controller is moved from notch to notch. The small current in the split phase coil has the effect of demagnetizing the cores, and thus prevents them from being held up by residual magnetism.

Each motor coach carries a two-pole 6-h.p. motor for driving the air compressor which supplies air to the Westinghouse brakes and gear controlling the bows. Owing to the fact that the height of the overhead wires varies considerably (there being a difference of as much as 6 ft.), great care had to be exercised in the design of the bows, and the height of the coaches had to be made lower than the normal height. To obviate the necessity for employing low passenger coaches, it was decided to fix the bows on the guards and luggage compartments, but even here the clearance available for the bow and its framework (all of which it is to be remembered are alive) is only a little over 11 in. when the bow is in the lowest working position. It was not easy to construct a bow suitable for meeting the conditions prevailing. The design of the bow finally adopted resembles that shown in position on top of one of the coaches (Fig. 29). Two bows are fitted to each motor coach; one is brought into use for each direction of travelling. When the driver operates the reversing handle for changing the motor connections, one bow is lowered and the other raised so as to be ready for the new direction of running.

Notwithstanding the extreme variation of the working height of the bows, the pressure exerted on the wire remains practically constant. Deep grooves have been made in the aluminium contact strips, and they are filled with vaseline and black lead which give efficient lubrication, and experience has shown that, under normal working conditions, the strips will run 5,000 to 6,000 miles before repairs become necessary, and that with proper inspection they wear very evenly, and there is little tendency for grooves to form. The width of the collecting strips is 3 ft. 7½ in., and that of the bow over all, 5 ft. 4 in.

The repair shops for the South London line are situated near Peckham Rye, and consist of two bays into one of which the trains can be run for inspection. This bay has two sets of rails laid above inspection pits, each track being long enough to accommodate a complete train. The other bay is divided into two halves, one half has two storeys; the lower part serving as a stores, whilst the upper portion is used for repairing motors, etc. The single storey portion, shown in the foreground of Fig. 30, is provided with an inspection pit and contains lathes and drilling machines for the general overhaul of motor bogies. A 5-ton overhead travelling crane worked with three single-phase motors is in use in this shop. This crane serves for lifting the rotors and stators to the second floor, which, as already explained, is reserved for the repair of those parts. There is also a 20-ton electric crane in the other bay, which besides being used for general purposes, is also employed in the manner shown in Fig. 31. By means of a clamp arrangement attached to the crane swivel, the end of a coach can be lifted when the bogie below can be shifted from beneath the coach with the greatest ease. In practice, it has been found possible to change a motor bogie in less than fifty minutes. All the machine tools are worked with single-phase motors, likewise the 20-ton crane. For lighting purposes metallic filament lamps are used, some giving 400 candle power, the pressure of the lighting circuit being 150 volts. The motors used for driving the cranes, capstans, etc., are designed for a pressure of 300 volts. There are no overhead conductors in the Peckham repair shops. The coaches either run into the buildings by their own momentum, or are pushed in by a train behind. They are hauled out by means of electric capstans.

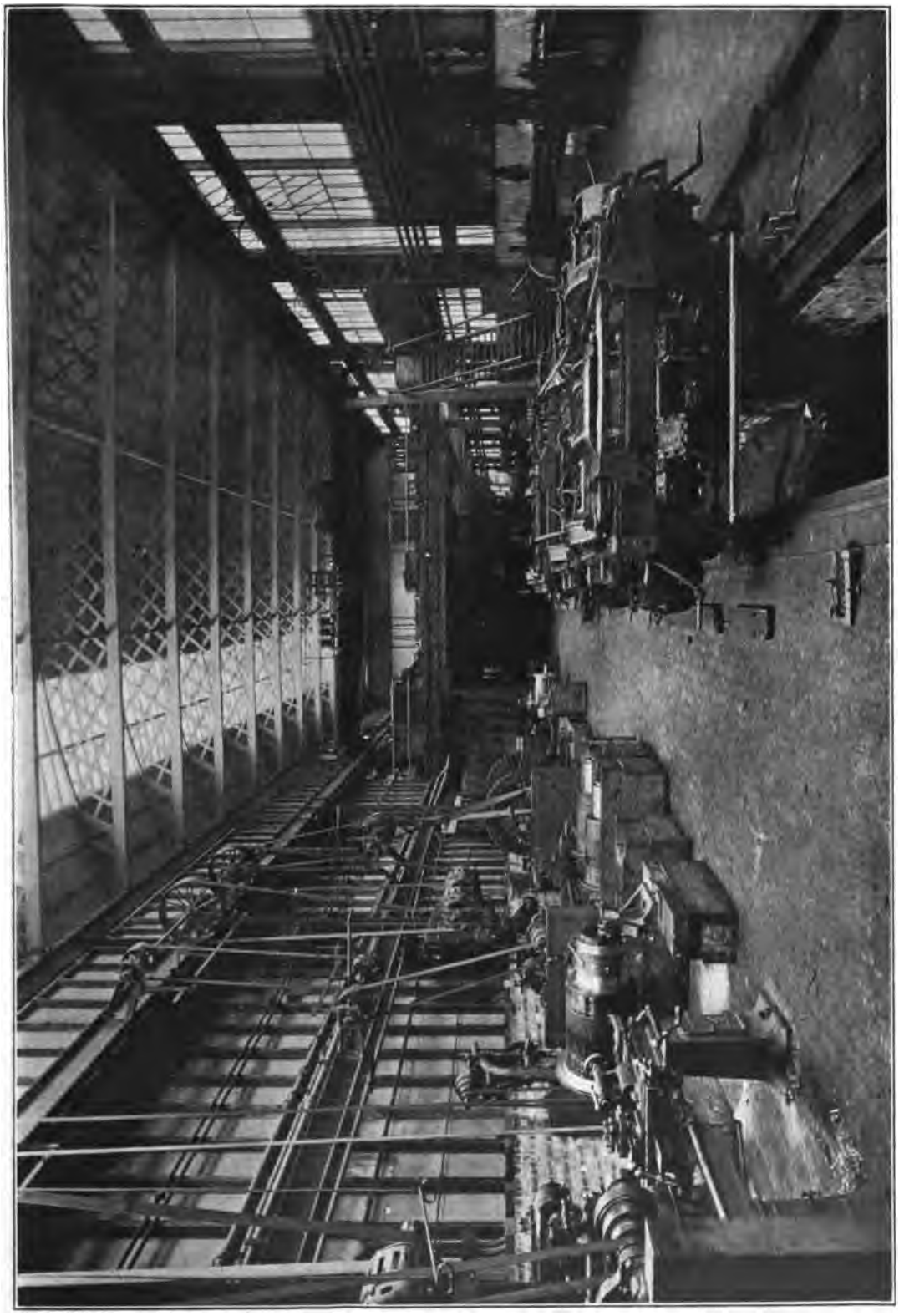


FIG. 30.—Repair Shop.

When the Crystal Palace scheme was carried out repair shops were also erected at Norwood Junction, but the principal shops are those at Peckham Rye; the others are used mainly for small repairs, which are found to be necessary when daily and weekly inspections are made. When the motor coaches have run about 60,000 miles, the electrical equipment is dismantled and thoroughly overhauled. All this work is carried out at Peckham. In the case of the shops at Norwood, high tension wires have been erected inside, so that the trains can be worked with the single-phase current in the same manner as when they are on the outside track. But the overhead lines in

FIG. 31.—Carriage-lifting Crane in Repair Shop.

the shops are independent of those in the yards, and the current can be cut off when desired.

For repairing the overhead lines outside, petrol electric coaches are used as shown in Fig. 32. These are fitted with Daimler engines and electrical equipment built by Dick Kerr & Co. During the day the overhead lines are inspected by means of field glasses, and any faults discovered are reported and duly attended to by the repair staff at night.

Much might be written on the electrified lines of this railway, but enough has been said to give a fair idea of the general character of the work, and to enable the reader to understand why the single-phase system was adopted.

FIG. 32.—Repair Wagon.

THE MIDLAND RAILWAY

On this railway about twenty-one miles of single track have been electrified, the electrified portion comprising the double road between Heysham and Morecambe,

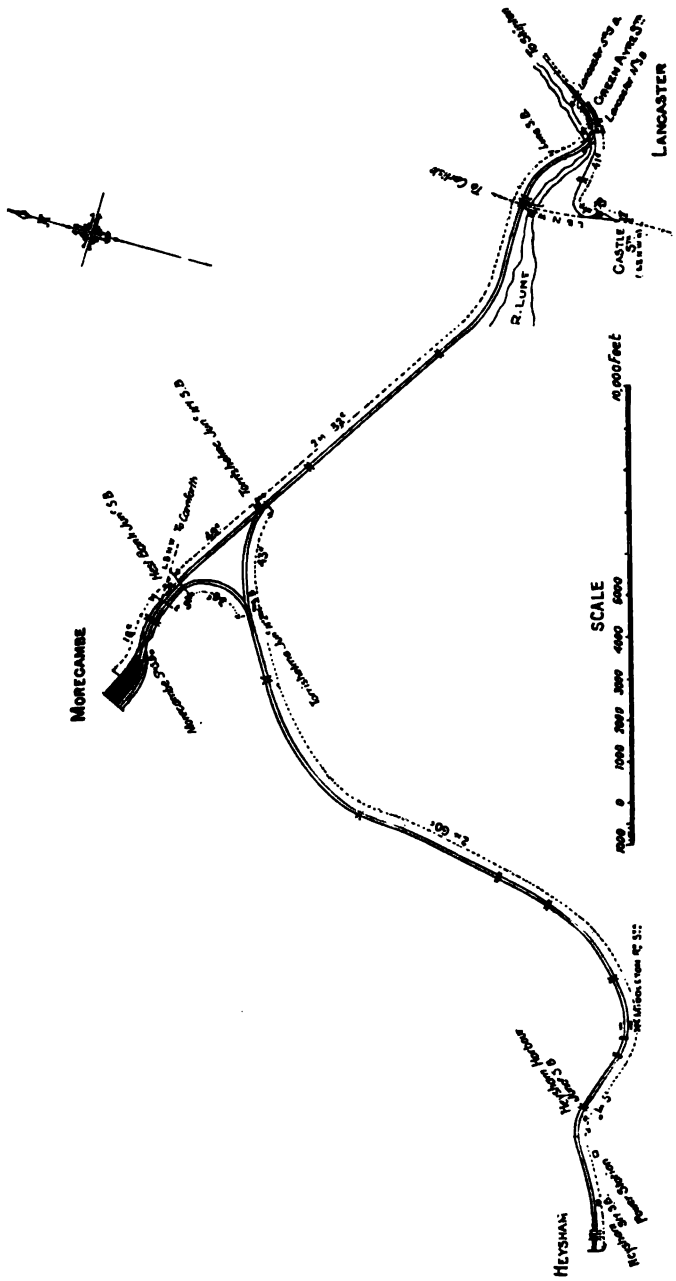


Fig. 33.—Plan of Line, showing Over-bridges, etc.

Morecambe and Lancaster Green Ayre, and the single line from Lancaster Green Ayre to Lancaster Castle. The plan (Fig. 33) shows that the lines pass under a large

number of over-bridges, many of which are of the arched type. Difficulties were experienced in erecting the overhead equipment at these points owing to the small clearances. Another plan giving the gradients is shown in Fig. 34. The overhead lines are similar to those on the Hamburg-Altona Railway, electrified on the single-phase system by Siemens-Schuckert.

The contact wire, which is in lengths of from 800 to 1,000 yards, has a section resembling the figure 8, the sectional area being 70 sq. mm. Details of the overhead construction are shown in Figs. 35 to 37. One end of each length of the contact wire is fixed by insulators to a terminal gantry and the other end is connected after passing

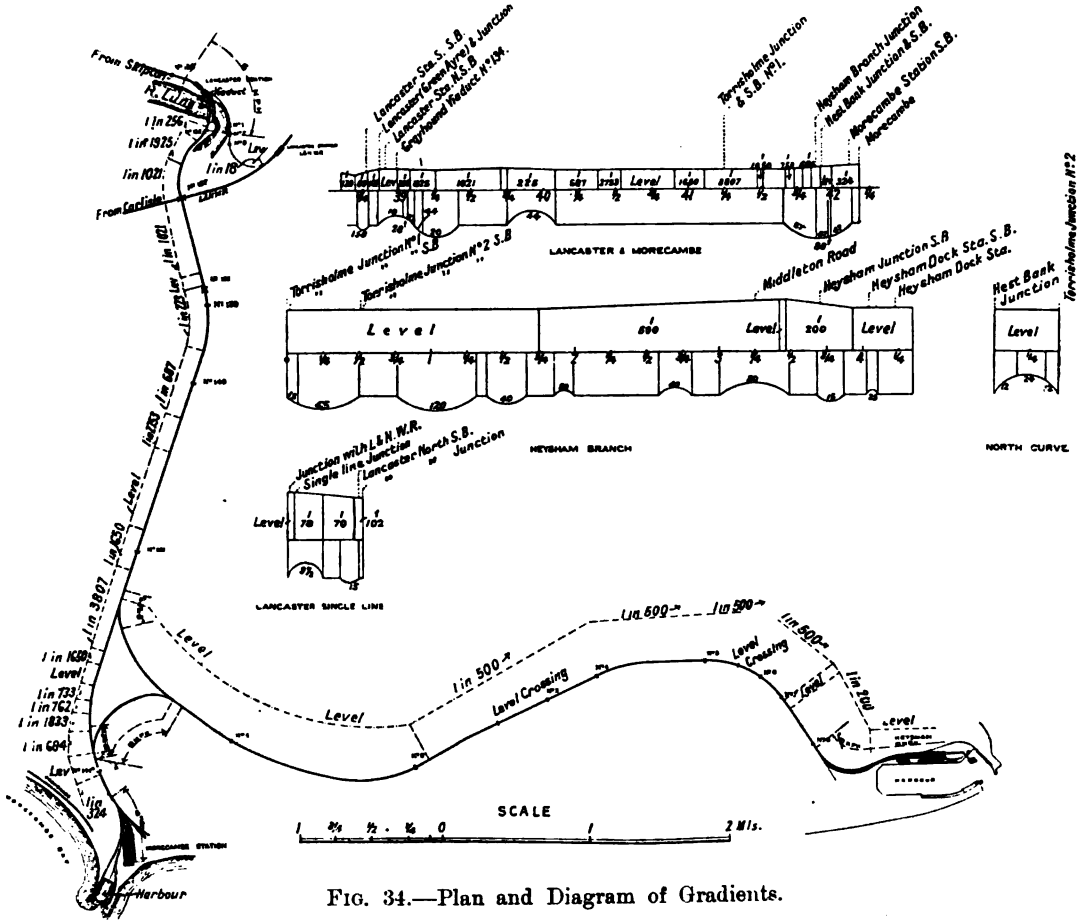


FIG. 34.—Plan and Diagram of Gradients.

over pulleys to a weight of about 1,200 lbs. The bows on the motor coaches always move in a direction away from the fixed end of the conductor, and consequently always tend to tighten the wire. Views of the overhead equipment at junctions are given in Figs. 38 and 39. Originally the tension on the wire was 800 lbs. and the horizontal stagger 4 ft.—that is to say, 2 ft. from the centre of the coach. Experiments carried out before the line was opened indicated that a pull of 800 lbs. was insufficient. Friction introduced by the pull offs, etc., prevented the wire being properly tightened, and it was found necessary to increase the weight to about 1,200 lbs. for a length of 1,000 yards. It was also discovered that a 4-ft. stagger for a bow measuring 7 ft. 1 in. from tip to tip was excessive when the trains were running at high speeds.

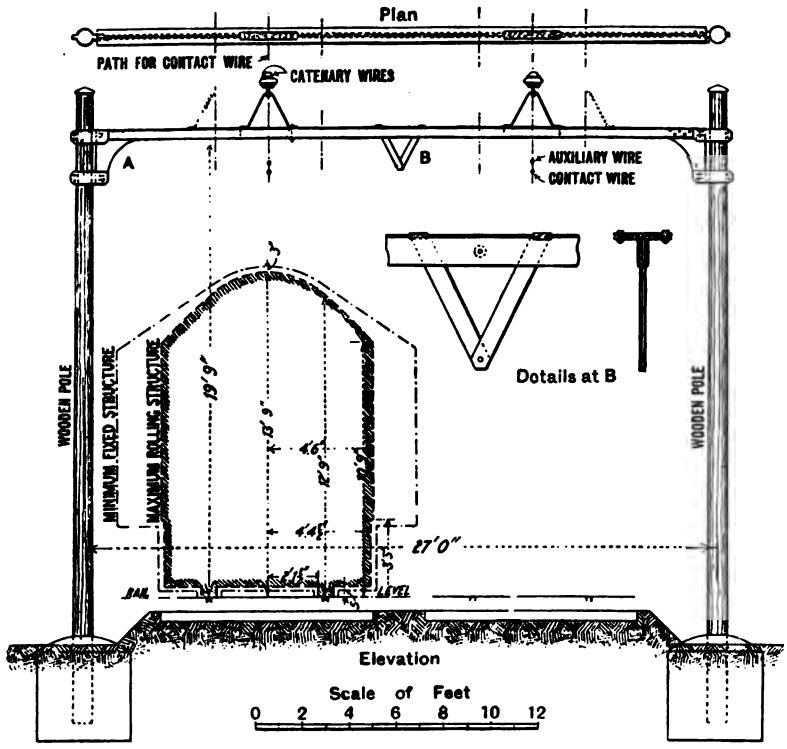


FIG. 35.—Details of Overhead Construction.

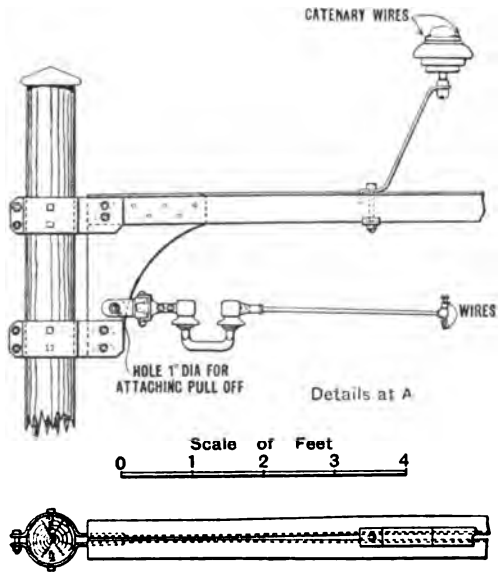


FIG. 36.—Details of Overhead Construction.

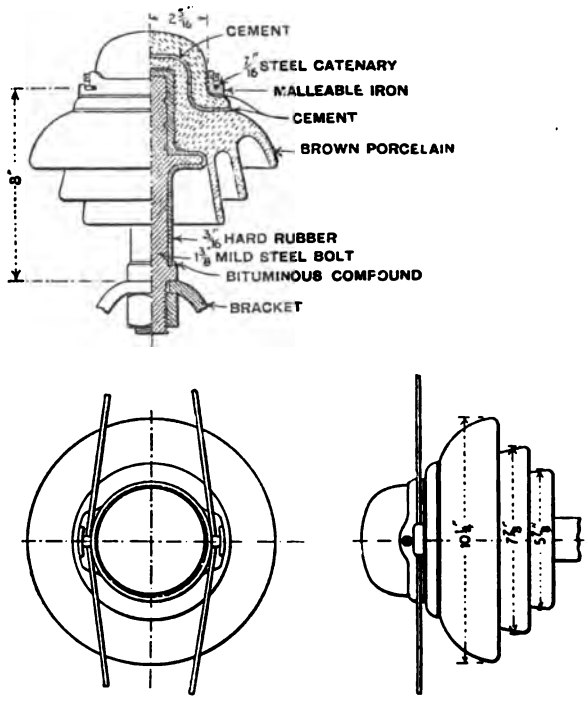


FIG. 37.—Details of Insulator.

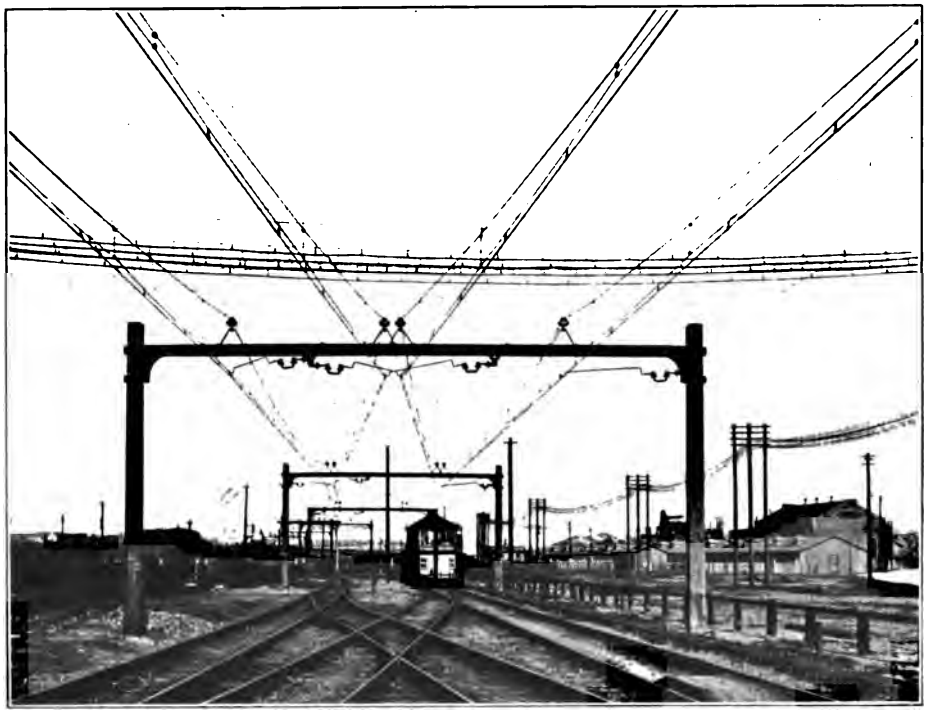


FIG. 38.—View of Overhead Construction.

FIG. 39.—Overhead Wires at Junction.

Violent gales are frequently experienced in this part of the country, and this is one reason why it became necessary to reduce the stagger of the overhead conductor. On the greater portion of the lines it has been reduced to 2 ft. The height of the conductor from the rail level varies from 18 ft. 3 in. in the open to 13 ft. 3 in. under bridges. The wire is suspended by short loops about 4 in. long from a steel auxiliary wire. These loops are fixed to the contact wire, but are capable of moving with respect to the auxiliary wire. The latter consists of a 7/13 steel flexible cable, and it is suspended from two catenary cables at five points in each catenary span as shown in Fig. 38. Each catenary cable is composed of seven No. 16 gauge steel wires. They are clipped together, except for a distance of about 3 ft. on either side of the insulators, where they divide to pass through the grooves in the insulators, as shown in Fig. 37.

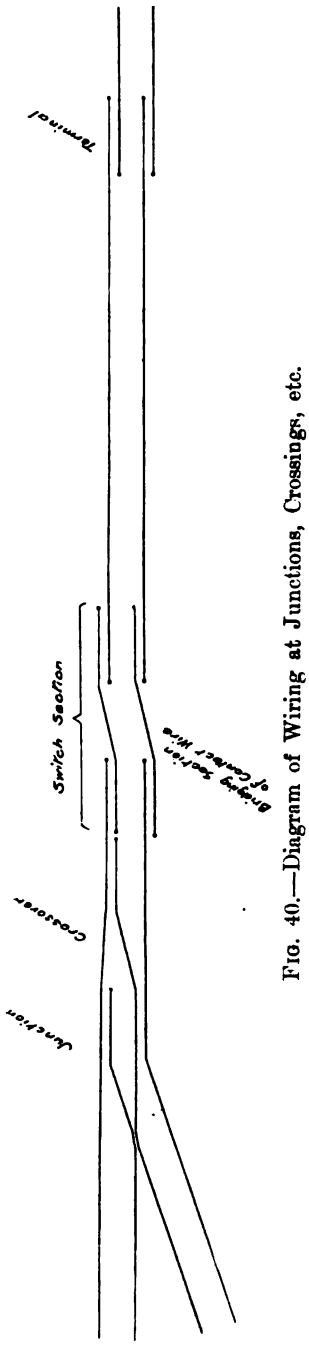


Fig. 40.—Diagram of Wiring at Junctions, Crossings, etc.

Therefore the catenary is free to move through this distance, thus equalising the stresses set up in the spans by unequal loading. At the same time experience has shown that the overhead construction remains secure in the event of one of the catenary cables breaking. Various advantages are claimed by Siemens Brothers for this type of overhead construction. The number of droppers is considerably reduced, the tightening and adjustment of the contact wire is facilitated, no distortion of the droppers occurs when the contact wire is tightened, the maintenance cost is low, and lastly, if the contact wire breaks the suspension wires are not pulled down with it. It is possible to isolate sections of the contact wires on the up and down lines, and for this purpose duplicate double break section switches are fitted. They are fixed at the tops of the poles which support the gantries, and the connection from one contact wire to the section ahead of it is made by a short piece of wire, the ends of which must be connected to the ends of the sections of the contact lines before a circuit between the two sections can be established. There were two reasons for adopting this system. In the first place, it was considered desirable that there should be a double break, and secondly, it was deemed advisable to have a short length of line between the sections into which coaches can be run. In this way the bow on a motor coach is prevented from bridging the sections it is desired to isolate. Padlocks are used for locking the switches. Similar switches are used at the stations for earthing the overhead lines in case of emergency. A wiring diagram is given in Fig. 40. The gantries are connected together by a separate overhead steel cable, which is connected to earth plates every half-mile. All the lightning arresters are also connected to these plates. The lightning arresters are of the horn type. With the object of reducing the electrostatic charges, the earthed conductor has been placed between the contact wire and telegraph wires, on one side of the

track. It was the object of the engineers of the company to avoid cabling the telegraph and telephone wires, and the experience gained seems to indicate that this is unnecessary when the single-phase system is used. But it is considered that the provision of some sort of high resistance leakage device is desirable, for when a telegraph or telephone wire is put out of service and disconnected at the test board, there is the possibility of a high potential existing between it and earth.

Most of the supporting poles are of creosoted wood, but owing to the long spans at Morecambe station and at one or two other points it was necessary to employ lattice steel poles and lattice girder gantries at these localities. Where wooden poles are employed the gantries are composed of two angles brought together at the ends but separated for the greater part of their length by a distance piece about 1 in. thick. The bolts which hold the insulator saddles pass through the gap, thus enabling the positions of the insulators to be adjusted with ease. The type of insulator used is shown in Fig. 37. From the sectional view it will be seen that the steel bolts which support the insulator are enclosed in an ebonite sleeve, this construction giving extra strong insulation. The insulators are made in two portions and are massive. On each track the outer rail is bonded throughout its length with duplicate bonds of the Forest City type, placed underneath the fish plates. At crossings and junctions all the rails are connected together in order to ensure good continuity. The bonds used at these parts and those employed for cross bonding are of the ordinary copper cable type. In bonding the line care was taken to prevent moisture getting into the drilled holes or on to the bond plugs, and during very wet weather the work was stopped. By taking special precautions it was found possible to proceed with the work during moderately wet and damp periods, but when resistance tests were carried out on the completion of the job it was found possible to distinguish the bonds that had been worked upon when the weather was damp or wet. The resistance of the joint in these cases was a little in excess of that of the other bonds, but in all cases the results were satisfactory.

At Heysham harbour the rails are connected to two copper earth plates placed in the sea. They are also earthed at the end of the Midland Railway pier. These plates are also of copper, but for protection they are placed in a large cast-iron caisson. The rails are also connected to a bridge at Lancaster, the columns of which are in the bed of the river. The line is supplied with current from the Midland Railway Company's power station at the Heysham end. The station was built for providing current for working cranes, capstans, lifts and other machinery in the harbour at Heysham, and also for lighting the harbour. Prior to the opening of the electrified line it was a direct current station pure and simple. It was, therefore, necessary to put down special plant for the production of single-phase alternating current. The station contains gas engines supplied with gas from Mond producers. Originally there were three 250-h.p. engines built by the British Westinghouse Company, each coupled to a 150-kw. dynamo, working at a pressure of 460 volts. For the purpose of supplying current to the electrified lines it became necessary to put down an additional set consisting of a 350-h.p. Westinghouse engine and a 235-kw. 460-volt continuous current generator. In order to obtain single-phase current for the railway two motor generators were installed. Each motor generator is supplied from the low tension continuous current bus bars. The alternating current side of each converter is connected to the single-phase bus bars by means of a hand-operated oil switch, and the current passes from the bus bars through duplicate circuit breakers to two feeders which are joined up to the overhead lines. There are no other feeders. All circuit breakers are fitted with time limit devices. Fig. 41 gives a view of the interior of the engine room.

The rolling stock consists of three trains, each made up of a single motor coach and trailers. The electrical equipment for two of the motor coaches was manufactured by Siemens Brothers, and that for the other coach by the British Westinghouse Company. The control system adopted by the former firm is purely electric, whilst that used by the Westinghouse Company is electro-pneumatic. Four trailer coaches were specially built for use on the electrified lines. Old bogie coaches are also employed for carrying luggage, etc., particularly between Morecambe and Heysham. Controlling equipment is fitted at each end of the motor and trailer coaches. This was necessary on account of the fact that the length of the train varies, for during different parts of the year there is a great difference in the amount of traffic. The distance from Heysham to Morecambe is five miles and that from Morecambe to

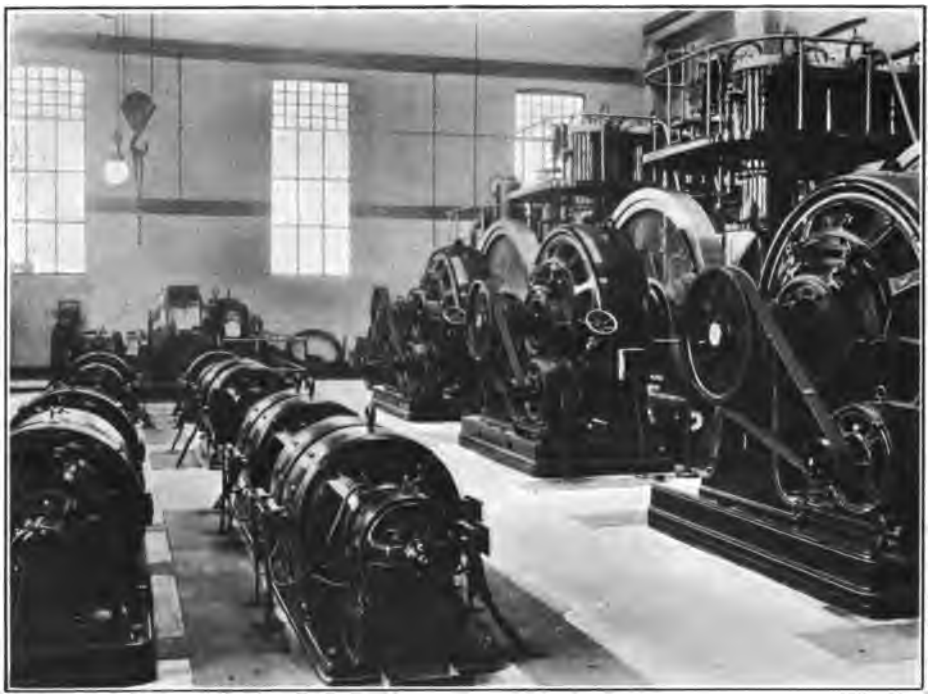


FIG. 41.—Interior of Power House.

Lancaster four miles. There is a short extension of about three-quarters of a mile from Lancaster Green Ayre to Lancaster Castle. All the distances with the exception of the latter have been increased by a quarter of a mile since the scheme was decided upon, owing to the company having changed the position of the station at Morecambe. There are no gradients of importance on any section of the line, except between the two Lancaster stations.

The motor coaches are of the open central corridor type, the total length over the end panels being 60 ft. The width is 9 ft. There are three compartments, providing seating accommodation for seventy-two passengers. The seats in the middle compartment are arranged transversely. This compartment is 25 ft. long. The seats in the other two compartments are arranged longitudinally, this arrangement enabling trap-doors to be provided for inspecting the motors. These compartments are 13 ft. 5 in. long. The trailing bogies are of the Midland Railway Company's standard type and are composed of pressed steel members. The wheel base is 8 ft. All the coaches are

fitted with hand and power brakes; the latter are of the vacuum type. Independent motors are used for driving the vacuum pumps.

Each trailing bogie wheel is braked on both sides. The total length of the trailer

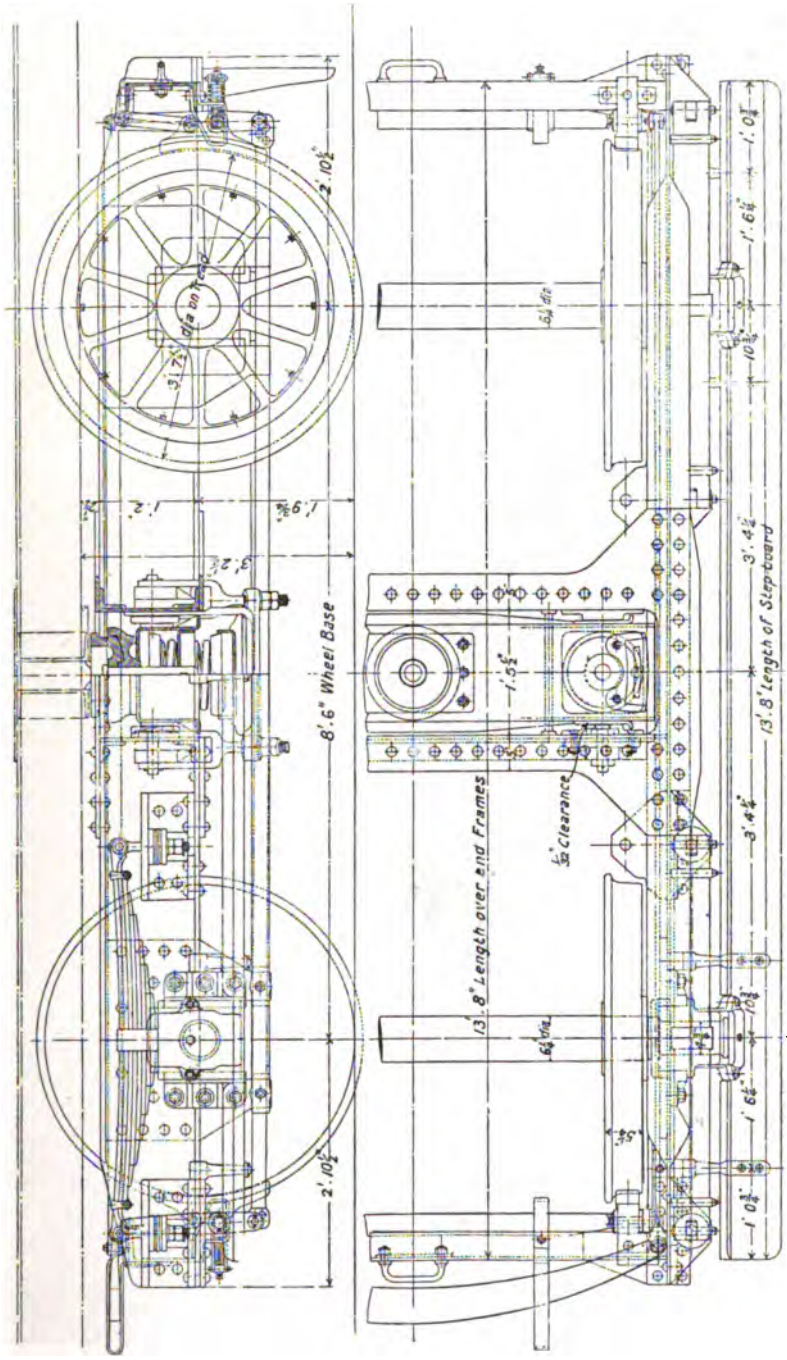


FIG. 42.—Elevation and Plan of Motor Bogie.

coaches measured over the end panels is 43 ft., and the extreme width 9 ft. There is one long compartment and a driver's compartment at each end. The seats, which will accommodate fifty-six passengers, are placed transversely. The two bogies are

interchangeable with the trailing bogie of the motor coaches. The motor bogies were constructed in the railway company's locomotive department, and owing to the small number required they were specially built up of rolled sections and plates. The wheel base is 8ft. 6 in.; the diameter of the driving wheels 3 ft. 7½ in. A view of one of the bogies as used on the motor coaches equipped by Siemens Brothers is shown in Fig. 43. Oil pumps are to be seen in the foreground and ventilating tubes on either side. Details of one of the motor bogies are given in Fig. 42.

Each motor coach has two brake cylinders, that for the motor bogie having special levers giving the cylinder greater purchase than usual. The trailer coaches have only one cylinder, which operates brakes on both bogies. A single brake pump is used for each coach. The control gear for the pumps gives two speeds. The pump control gear has been specially designed with a view to making it practically impossible for

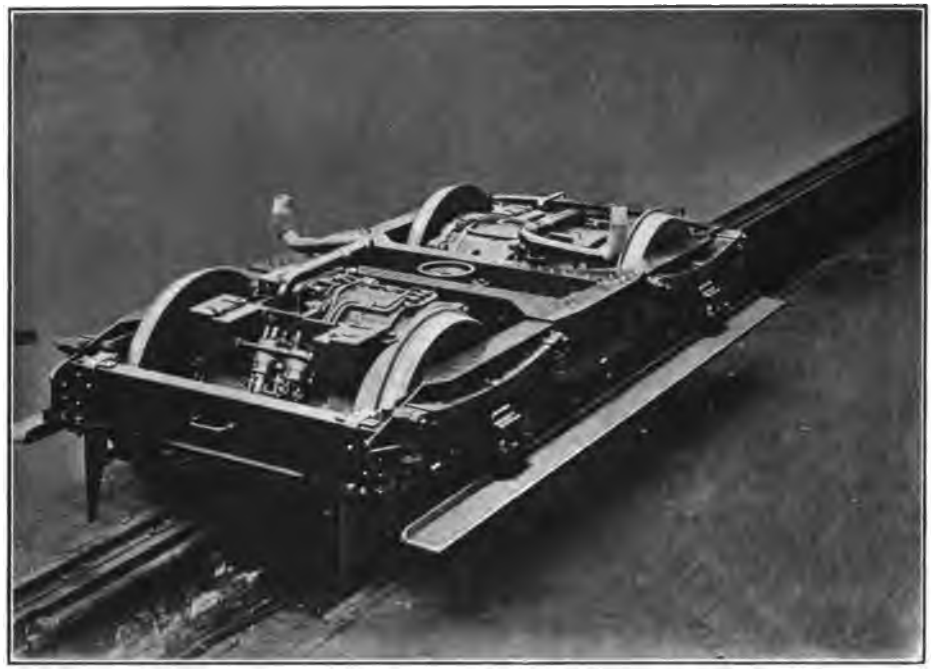


FIG. 43.—Motor Bogie Fitted with Siemens Equipment.

a train to be moved without the proper vacuum having been obtained. The driver's brake valve (Fig. 44) is combined with a switch which operates the contactors controlling the pump. Current is fed into this switch through one contact of a three-contact plug. One of the other contacts is in circuit with the feed wire from the auxiliary transformer, and the third is connected to the master controller. It is therefore impossible to move a coach by means of any of the controllers unless this plug is inserted in its socket. Its insertion automatically operates one of the pump contactors and starts the pump working at either the high or the low speed. Most probably the pump commences to work at the high speed, as the driver's brake valve handle is removable and it can only be taken off when it is in the full speed position. The provision of this plug also ensures that only one controller can be used at the same time. Naturally there is a brake valve in every driving compartment, but only the valve and switch in that compartment which is being used for driving, and in

which the plug is inserted, can be used for starting and varying the speed of the pump, but the brake can be applied by the guard or any other authorised person who may have access to the handle at either end of the coach.

Each coach is also fitted with a switch, which is controlled by the vacuum, its function being to trip the main circuit breaker in the event of the vacuum falling below 15 in. Each motor coach has two motors carried on a single bogie, as shown in Fig. 43. Trains usually consist of one motor coach and two trailers. The motor coaches seat seventy-two passengers, and the trailers fifty-four, the respective standing capacity being fifty-eight and thirty-six.

It was specified that the trains were to be capable of working on a twenty minutes service from either end of the line as between Heysham and Morecambe with a single train, and a fifteen minutes service between Morecambe and Lancaster under similar conditions. Each motor coach was to be capable of occasionally hauling two additional main line coaches each weighing 26 tons, and to be able to haul the train up the gradient between Lancaster Green Ayre to Lancaster Castle.

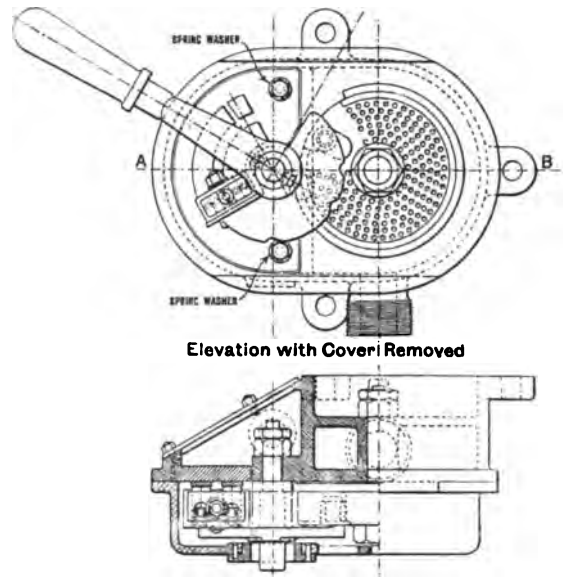


FIG. 44.—Details of Valve and Switch for Vacuum Brake.

FIG. 45.—Siemens Motor Coach

It was estimated that two 150 h.p. motors per motor coach would satisfactorily carry out the work, and the respective contractors supplied motors of their nearest standard size. Siemens Brothers supplied 180 h.p. motors, whilst the Westinghouse Company provided 150 h.p. machines. A coach built by Siemens Brothers is shown in Fig. 45. It will be gathered that there are two current collectors. A special type of bow has been adopted which is similar to the continental tramway bow, but having a small auxiliary bow at the end, controlled by parallel motion as shown in Fig. 46.

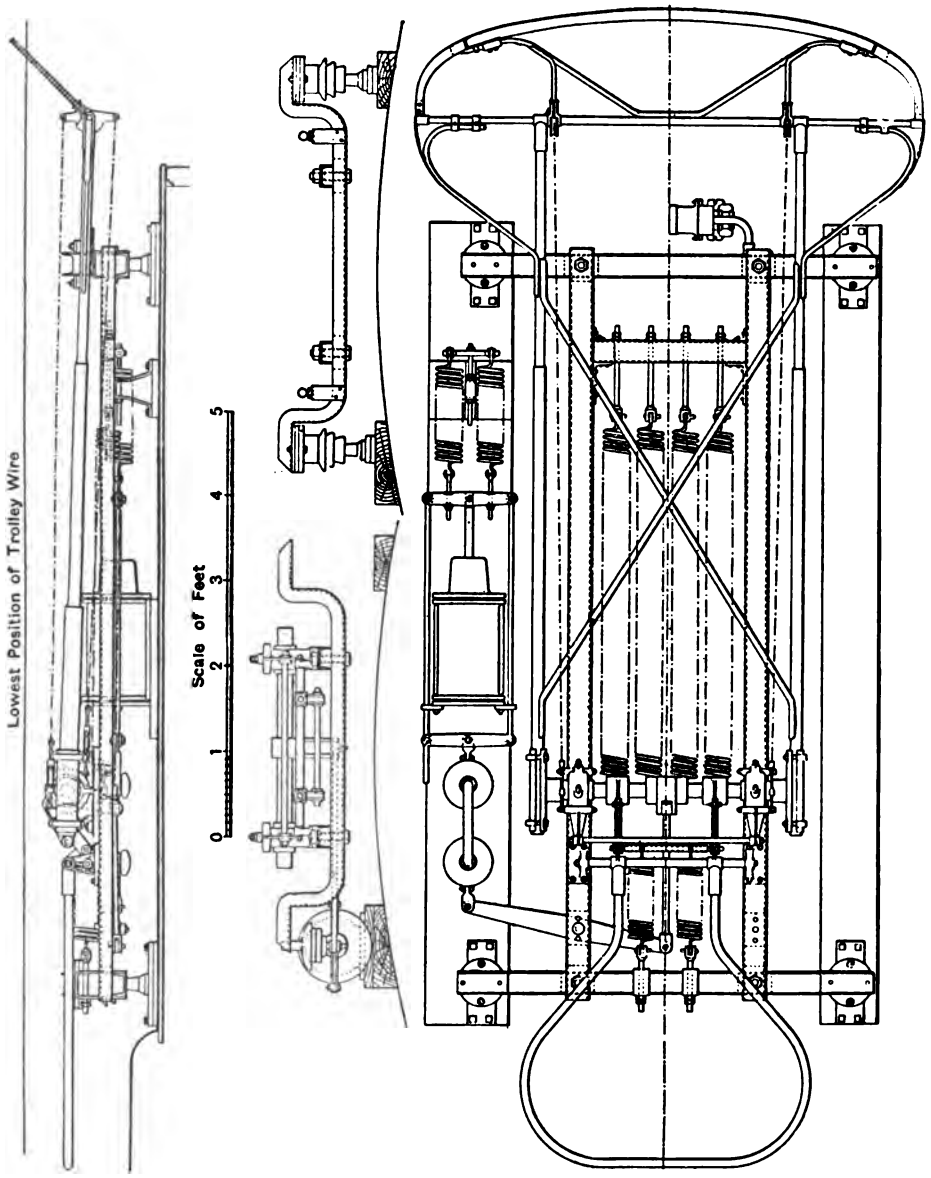


FIG. 46.—Siemens Bow.

The Westinghouse Company's coach has only one bow and is of the standard pantograph type. In each case the bows are controlled by springs. The Siemens bow, however, is lowered by a master spring which can be thrown out of action by a vacuum cylinder. The master spring of the bow fitted to the Westinghouse Company's motor coaches on the other hand, is controlled entirely with compressed air. A compressor is naturally fitted to the Westinghouse Company's motor coach. For the purpose

of operating the bows when starting out in the morning or at other times when no compressed air or vacuum is available, a small hand pump has been provided on all the motor coaches. The two bows on the Siemens coaches are raised or lowered separately. A ball valve is fitted on the compressed air pipe, so that when the brakes are operated the vacuum remains on the cylinders which control the bows. The shoe of the Siemens bow is made of aluminium, whilst that of the Westinghouse Company's bow consists of a flat piece of galvanised iron 6 in. in width and with the edges turned down. There is a groove of semi-circular section in which the lubricating substance is placed. The framework of the bows is built up of light steel tubing which serves to convey the current to the high tension cables. All portions of the collector gear which are subjected to the high pressure are carried on porcelain insulators. The roofs of the coaches are covered with wire netting which is earthed. Consequently, in the

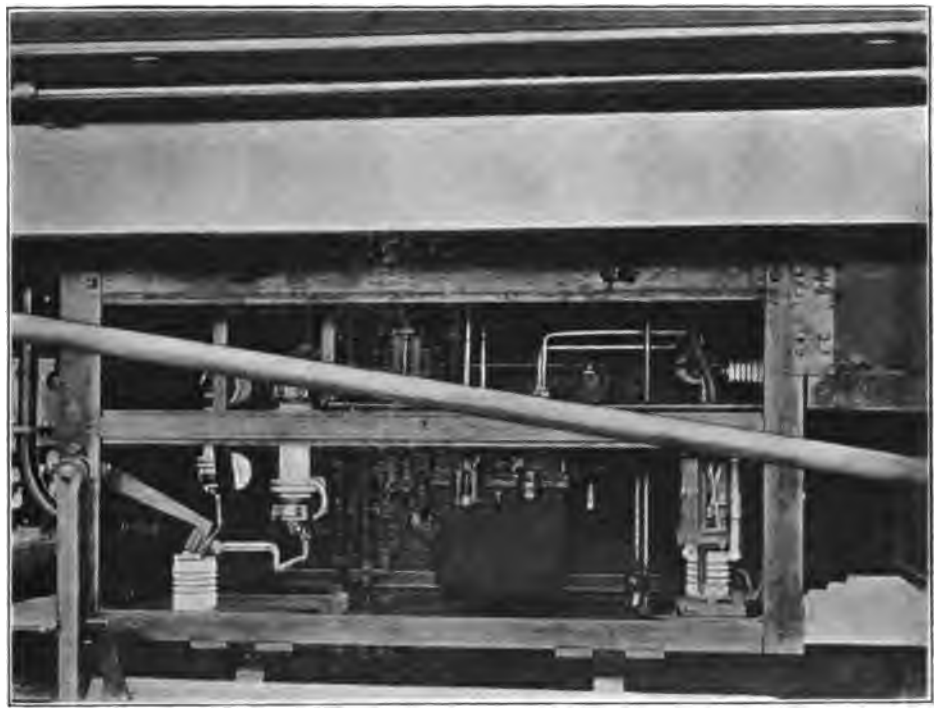


FIG. 47.—Siemens High Tension Chamber.

event of an overhead wire breaking and falling on top of a coach the circuit breakers at the station instantly cut off the current.

The Siemens high tension chamber containing the high tension switch, etc., is shown in Fig. 47. Like the main transformer, auxiliary transformer, preventive coil, and other apparatus, these chambers are suspended below the underframe of the coaches. The Siemens equipment consists of two motors, the main transformer, the auxiliary transformer and commutating transformer, high tension circuit breakers and fuse in the auxiliary transformer circuit; contactors, motor fuses and low tension fuses in the contactor circuit, and also a low tension fuse in the circuit feeding the fan. The weights of the various parts of the two types of motor coaches are given in the Table on p. 55. It should be pointed out, however, that the figures given in these tables do not represent latest practice, and that more modern equipment is probably appreciably lighter.

Temperature tests carried out at the maker's works indicated that the motors worked very satisfactorily. Sparking tests gave equally pleasing results. There was no objectionable sparking, even when the motors were taking 1,100 amperes at 300 volts. At full pressure (340 volts) this current corresponds to 350 h.p. and a torque fully two and a half times greater than that which exists at the rated output, namely 180 h.p. The commutating transformer used in conjunction with the Siemens motors appears to have a marked effect upon the performance so far as sparking is concerned.

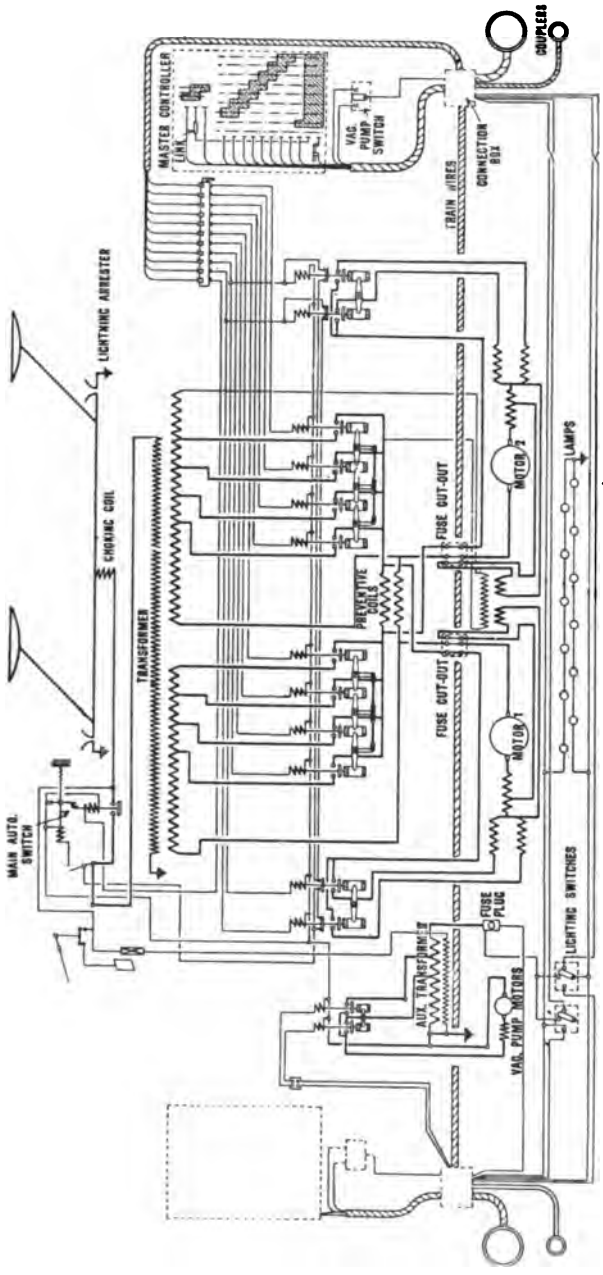


FIG. 48.—Diagram of Connections for Siemens Coach.

The motor controllers are of the fly-back or dead-man handle type, designed on somewhat novel lines, the special features being that the release of forward pressure on the handle trips the whole of the contactors at once, irrespective of the position of the handle. A diagram of connections for the Siemens coaches is given in Fig. 48. In the case of the Westinghouse motor coach, current is conducted from the pantograph bow by means of a lead-covered rubber insulated cable through a heavy brass conduit to the main circuit breaker. The circuit breaker is electro-pneumatically operated and breaks the circuit under oil. It opens automatically on overload and it is closed from the driver's cabin by placing the handle of the motor controller on the first notch. When the switch is closed the single-phase current passes into an oil insulated self-cooled auto-transformer, one end of the winding of which is earthed. Low tension tappings from the winding of the auto-transformer are connected to six contactors, which, as previously stated, are operated on the Westinghouse Company's electro-pneumatic system. This group of contactor-switches only weighs 854 lbs., and measures 43¼ by 24½ by 23 in. Electrical interlocking gear is fitted to the switches, so that they are compelled to close in the correct order. Powerful magnetic blowout coils are also fitted. Complete diagrams of connections

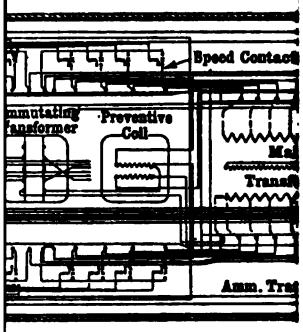


FIG. 49.—Diagram
E = Earth. U

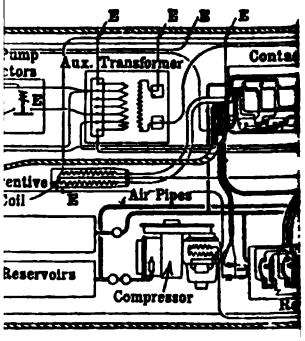


FIG. 50.—Diagram of
Compressor Governor. U

for each type of coach are given in Figs. 49 and 50. Fig. 51 gives a simplified diagram of connections for the motors fitted to the Westinghouse Company's coach. From this

	Siemens.			Westinghouse.		
	T.	cwt.	qr	T.	cwt.	qr.
Carriage body work	13	5	0	13	5	0
Carriage bogie	4	10	0	4	10	0
Special supports	1	6	0	0	17	0
Motor with gear and gear case	6	5	0	5	11	0
Main transformer	2	14	2	2	11	0
Auxiliary commutating transformer and preventive coil	0	19	2	0	9	2
Pumps and compressors	0	9	2	0	16	0
Contactors and chambers	1	2	2	0	9	3
Other sundries, including bows, blowers controllers, etc.	3	7	0	2	9	3
Motor bogie	6	11	0	6	11	0
	40	10	0	37	10	0

latter diagram it will be seen that the current passes from the contactors to the two terminals of the preventive coil from the middle point of which the cable running to the reversing switch is connected; the latter, like the contactors, is operated with compressed air.

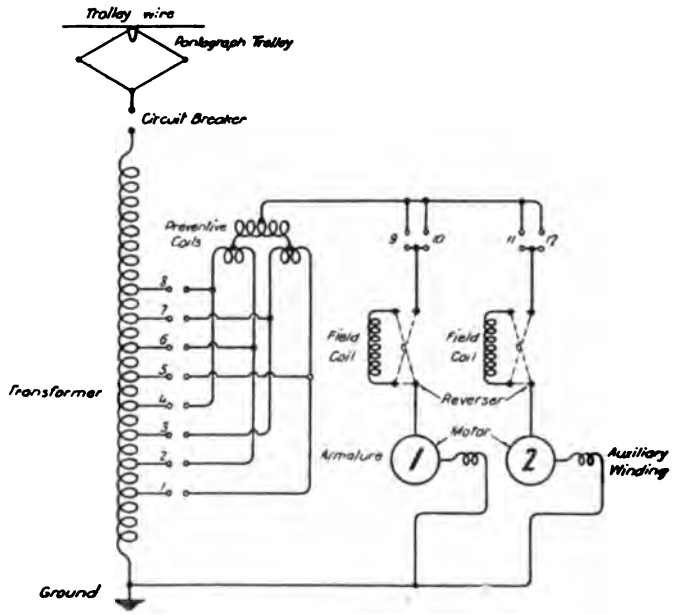


FIG. 51.—Simplified Diagram of Connections (Westinghouse Coach).

The magnet valves on the reversing switch are interlocked with those on the main group of contactors, so that it is impossible to close any of the latter until the reversing switch has been set. Cut out switches are fixed in the case of the reversing switch so that either of the two motors may be disconnected if desired. The motors are of the Westinghouse Company's standard series compensated forced ventilated type. A cross-section of one of these machines is given in Fig. 52. They are six-pole motors. Air from the blower is admitted at the pinion end, and having passed through the motor it leaves by way of the perforated commutator cover.

The electrical equipment was designed for operating a train weighing 82 tons in service. It has been found, however, that a considerably heavier train can be hauled. In fact a train made up of seven ordinary vehicles without the motor coach, and weighing 161 tons, has been run between Lancaster and Morecambe. On starting with this load each motor takes about 1,050 amperes. A train of this weight can be accelerated rapidly and smoothly and can attain a speed of fifty miles per hour.

The auxiliary transformer used on the Siemens coach is not only useful in connection

with the control gear, but it also eliminates the possibility of the lights being extinguished in the event of the high tension circuit breaker opening when an overload is thrown on the motors. Moreover, during a great portion of the year the coaches stand

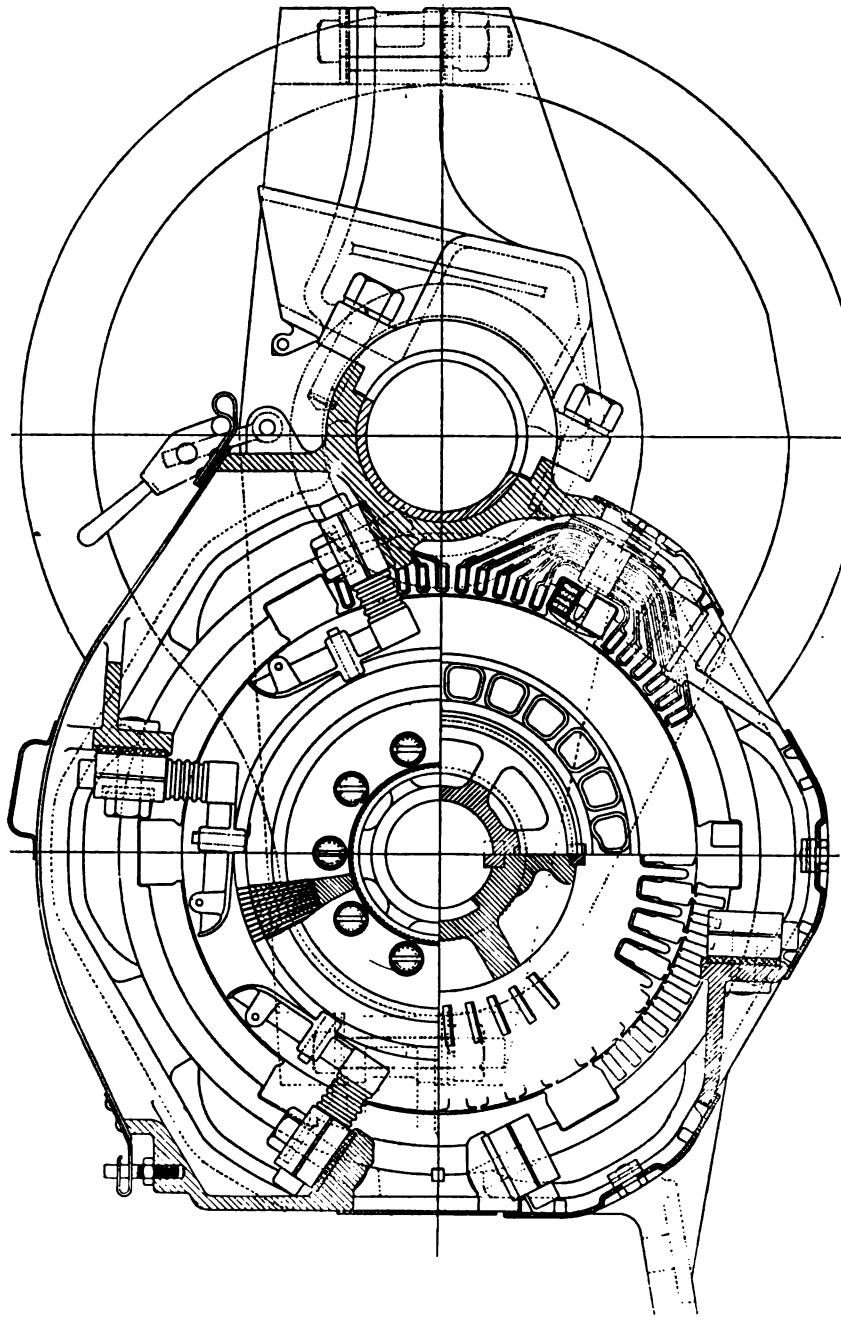


FIG. 52.—Westinghouse Single-Phase Motor.

in the stations for long periods, and therefore a slight saving of energy results from the practice of switching off the main transformer. But on the Westinghouse coach the main transformer is always in circuit, except, of course, when the high tension circuit breaker is opened. The pressure adopted is 6,600 volts, and the periodicity twenty-five cycles per second.

CHAPTER III

THE MIDI RAILWAY

THE question of electrifying certain sections of the Midi Railway in France has been under consideration since 1902. The line from Villefranche-de-Conflent to Bourg-Madame (Pyrénées-Orientales) has been worked electrically for several years. This section is 55 km. long, the gauge 1 m., and the steepest gradient 6 per cent. Current is derived from a 5,000-h.p. hydro station on the river Têt at La Cassagne. The line forms a continuation towards the Spanish frontier of the main line of the railway from Perpignan to Villefranche. This latter portion is about 46 km. long. Its gradients do not exceed 2·2 per cent.; the average is 1·7 per cent. At the time of writing it is being electrified on the single-phase system. Current is to be obtained from a second hydro station of 4,500 h.p. at Fontpédrouze, utilising a fall of 183 m. on the river Têt. But this only constitutes a very minute portion of the work which will ultimately be undertaken on the Midi Railway. The whole of the lines to be electrified may be divided into two groups, eastern and western, the former in L'Ariège and the Pyrénées-Orientales, the latter in the Haute-Garonne, the Hautes and the Basses-Pyrénées.

In the eastern group there is the Villefranche-Bourg-Madame line already electrified, and that from Foix to Aix-les-Thermes, which is being extended towards the Spanish frontier. In the western group there are the lines from Montréjeau to Pau, Pau to Oloron, Montréjeau to Luçon, Lourdes to Pierrefitte, Tarbes to Bagneres-de-Bigorre, Buzy to Laruns, and Lannemezan to Arreau, representing in all 350 km.

For the purpose of supplying current to these lines, as well as to further extensions, some high-power hydro-electric stations are to be built. It is anticipated that in addition to the stations at La Cassagne and Fontpédrouze, a third station at Porte, in the valley of Carol, will be necessary for working the lines included in the eastern group This station will be worked from the waters of the Lake Lanoux. For the western group it is proposed to erect three stations, situated in the valleys of La Neste, Gave d'Oloron and Gave de Pau.

The first station of 10,000 h.p., at Eget, in the Valley of Aure, will be supplied from a reservoir on an effluent of the Neste. It will contain four generating sets, each developing 3,500 kilovolt-amperes at 6,000 volts. The pressure will be raised to 60,000 volts by means of transformers. The height of the fall is 700 metres, and the output 2 cubic metres per second. The second station will be situated on the Gave de Soussoucon, a tributary of the Gave d'Oloron, above the Eaux-Chaudes. The third station is to be worked with the waters of the Gaves Gavarnie and Cauterets, for it is situated at the junction of these rivers, near the village of Soulom (Hautes-Pyrénées). This station will eventually consist of two parts. Each of the falls—117 m. and 258 m.—is to operate three turbines, each having a capacity of 3,500 h.p. The alternators are to generate single-phase current at 6,000 volts, but this pressure will be raised to 60,000 volts by means of static transformers. Current at this voltage will be transmitted to sub-stations at Lourdes, Pau, Tarbes, Lannemezan, and Montréjeau, where it will be transformed down to 12,000 volts, for use on the track.

This is the pressure that has been chosen for the Midi Railway. The periodicity is $16\frac{2}{3}$ cycles.

In order to study the relative merits of the locomotives manufactured by different firms, it was decided in 1910 to invite various electrical manufacturing companies to build single-phase locomotives to conform with the conditions prevailing. These engines were to be tested by the railway authorities, and it was agreed that, if found satisfactory, they should be purchased. Six locomotives were built by six different firms, and submitted for trial during 1911 and 1912. The trials were carried out on the portion of the line from Perpignan to Villefranche which immediately precedes the railway from Villefranche to Bourg-Madame. This portion of the railway, which is 25 km. long, was chosen because it was possible to obtain current from the Cassagne sub-station at Villefranche. Moreover, the line has gradients similar to those on the other lines associated with the electrification scheme. Besides the transforming station at Villefranche, which receives three-phase, 20,000-volt, 25-cycle current from the Cassagne station, and distributes direct current

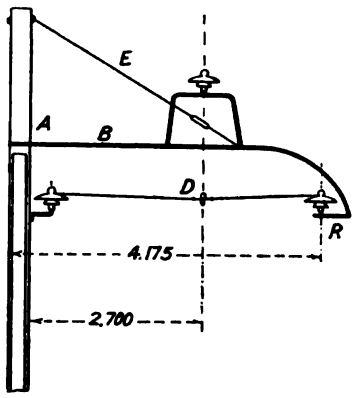


FIG. 53.—Overhead Construction for 50-m. Span.

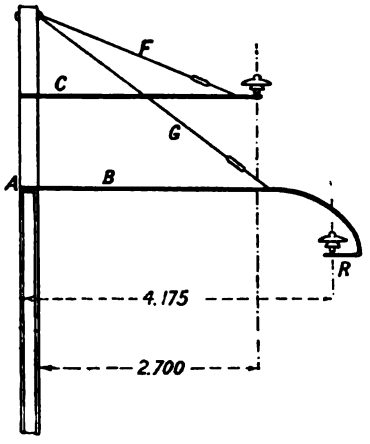


FIG. 54.—Overhead Construction for 100-m. Span.

to the railway from Villefranche to Bourg-Madame, a second sub-station has been erected for the purpose of the trials, and in this station the three-phase current is converted to single-phase current at a pressure of 12,000 volts.

It contains two sets, each comprising a three-phase induction motor and a single-phase alternator, together with an exciter. Transformers are interposed between the single-phase alternators and the overhead conductors of the railway. In view of the short length of this experimental line, there is only one feeding point, viz., at Villefranche. Six different types of overhead construction have been tried. One form of equipment, which was designed and erected by the French Thomson-Houston Company, is illustrated in Figs. 53 and 54. This company's overhead equipment extends from the kilometre post 497 · 927 to the post 501 · 894. Spans of 50 m. are adopted as far as the post 500 · 185, whilst the span between the poles on the remainder of the section is 100 m. The poles are of reinforced concrete, and their construction differs according to the distances between them.

In the case of the design shown in Fig. 53, which relates to a support as used for the 50 m. spans, the overhanging bracket B is composed of two pieces of angle iron assembled together and held in a horizontal position by a tie-rod E, which is

fixed to the top of the standard. The outer extremity of the bracket is bent towards the rails. The insulator which supports the catenary cable is mounted at the top of a light structure attached to the upper side of the bracket in the manner shown. An insulator is also mounted at the point R and another on the post directly opposite to it. A wire attached to these insulators serves to hold the contact wire in the correct position with respect to the track. The construction shown in Fig. 54 differs from the design just described in that there are two horizontal arms B and C; the former is supported by the tie-rod G and the latter by the tie-rod F. The catenary cable in this case is supported on the insulator mounted at the end of the arm C. This is the construction used where the span between the posts is 100 m. In all cases the insulators on the brackets are interchangeable. Fig. 55 shows the construction of an intermediate pole as used on curves.

The line consists of a steel supporting cable having a section of 37 mm.; also an intermediate cable having a diameter of 4 mm. This is suspended from the catenary cable by means of droppers, whilst the contact wire is supported by clips in the manner shown in Fig. 56. The intermediate wire is shown at A, the contact wire at B, and the clip at C. These clips allow the contact wire to be slightly dis-

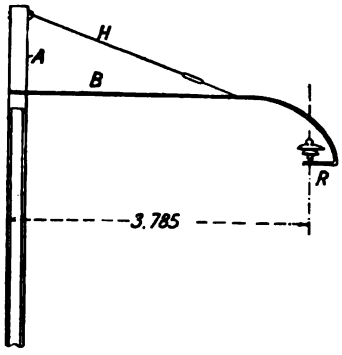


FIG. 55.—Intermediate Bracket as used on Curves.

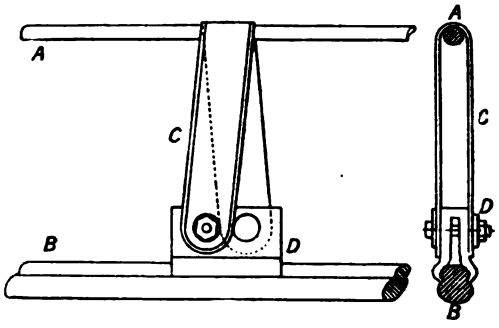


FIG. 56.—Details of Suspension Clip.

placed with respect to the wire immediately above it. In order to minimise wear on the bows of the locomotives the contact wire is mounted in a zig-zag fashion with respect to the rails. At the point where the spacing of the poles is changed from 50 m. to 100 m. the line is sectionalised. The wires of the two sections are brought near to one another and anchored to the posts, so that when a train passes from one section to the other there is no interruption in the supply. In the tunnel of Venta Farines the main carrying cable is dispensed with, and is anchored at the two ends of the tunnel. Within the tunnel the second or auxiliary wire is suspended from the transverse wires carried by insulators on the two sides.

The French Westinghouse Company has also devised overhead equipment. In this instance the posts are composed of old rails and furnished with horizontal brackets for carrying the suspension insulators. The conductor takes the form of a copper wire, which is attached to the catenary cable by hangers and to the posts by horizontal arms, permitting lateral movement. On one part of the line, where the span between posts is 100 m., tightening gear is employed, the wires being stretched by weights. A third system has been designed by the A.E.G. Company. The poles are of reinforced concrete, and are fitted with horizontal arms, which carry insulators and a cross wire, to which the conductor is attached. Here, again,

tightening gear is employed. Another firm which has built some overhead equipment is Vedovelli Priestley. This firm also uses reinforced concrete poles with iron brackets, the contact wire being hung from the catenary cable by droppers. Two systems of stretching the wire have been tried. In one instance a weight produces a pull on the catenary cable and contact wire, whilst in the other case the carrying wire is subjected to a pull by a weight and the contact wire by a spring.

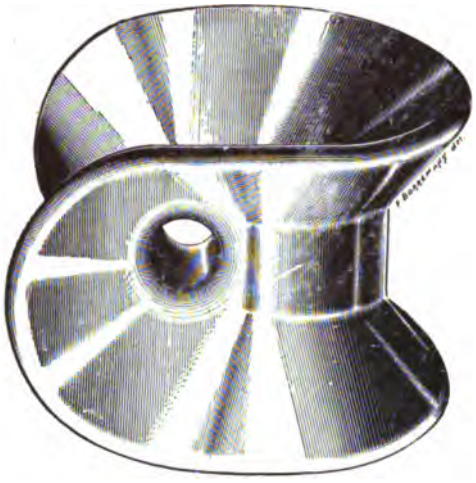


FIG. 57.—Link Insulator.

Attention should be directed to the firm's link insulators, for which various advantages are claimed. The general appearance of one of these insulators can be gathered from Fig. 57, whilst Fig. 58 shows how they are assembled in the form of chains for insulating and supporting the catenary cables and feeders on single-phase railways. Each link (see Fig. 58) is connected to its neighbour by a ligament of galvanised steel wires in such a manner that the insulating material is always in compression. It will be clear that in the event of one or more of the links breaking, the line which the chain supports cannot drop to the ground, although the insulation of the chain will naturally be diminished.

The distances between the links can obviously be varied as desired, and the greater the space between them the greater is the voltage necessary to break down the insulation. Tests carried out on an eight-link chain with the links spaced 50 mm. apart and subjected to an artificial shower of rain showed that a pressure of 90,000 volts was needed to break down the insulation, and a chain composed of six links spaced 90 mm. apart was found to be good for nearly the same pressure under similar conditions. The method of using these insulators on the Midi Railway will be understood from Fig. 59. Wood, reinforced concrete, lattice, or metallic tubular

FIG. 58.—Chain of Link Insulators.

posts are supplied by the firm, but apparently the reinforced concrete type has been found to present many advantages.

The general appearance of these posts as used on the Midi Railway can be gathered from Figs. 59 and 60. They are composed of four bars of steel with cross pieces at regular intervals, the whole being covered with concrete. It is claimed that the strength of these posts increases with time. They are built up and covered with concrete at the point where they are erected, and are supported in a bed of concrete. Not only do they present a good appearance, but they are also said to be cheaper than the ordinary metal posts. In the case of the Midi Railway they are placed on only one side of the permanent way and in a position which enables the

drivers clearly to see the signals. When wooden posts are employed the maximum distance between posts is 40 m.

Flexible droppers take the form of galvanised iron chains, as shown in Fig. 61; the upper ends are provided with small brass clips for fastening the chains to the

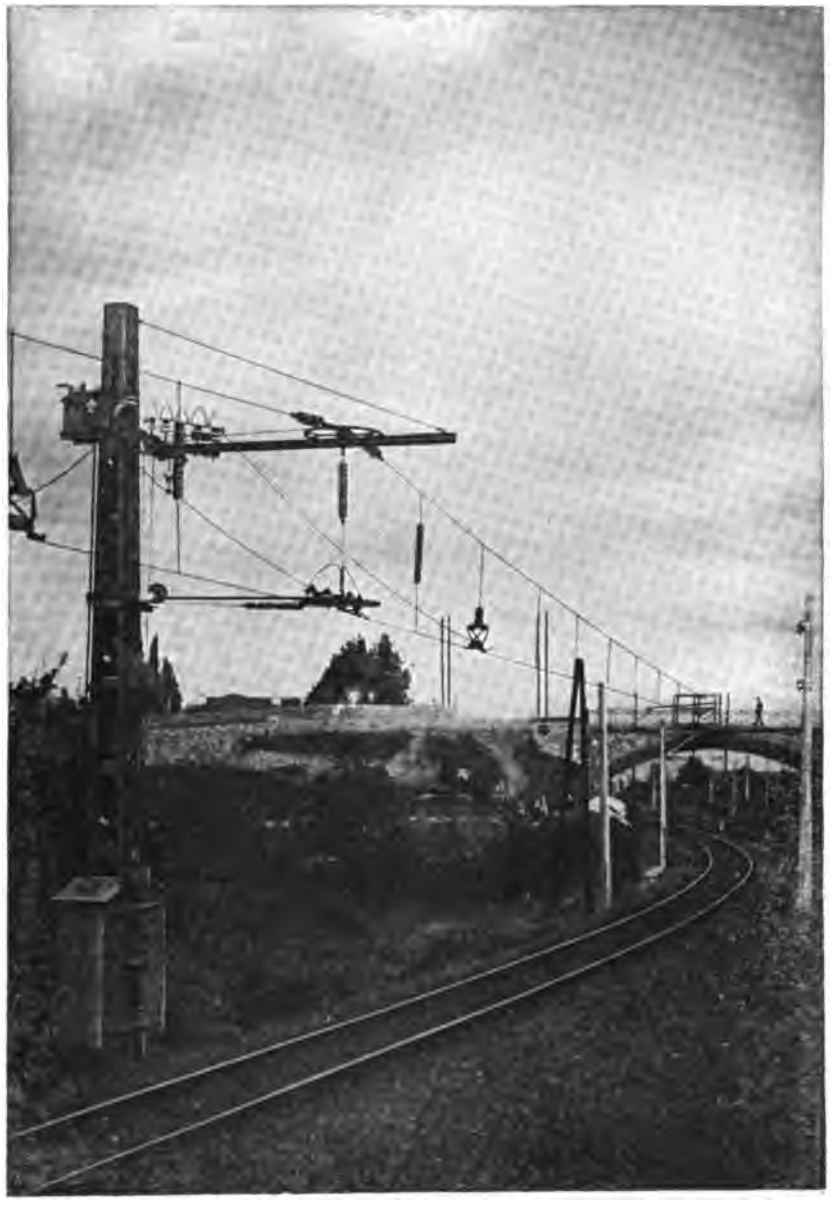


FIG. 59.—Sectioning Post.

catenary cable, and the lower ends are attached to galvanised iron clips. As the illustration shows, the jaws of these clips fit into the grooves on the two sides of the contact wire, and by inserting a split pin between the jaws the contact wire is gripped in such a manner that it is impossible for the wire to become unfastened. The sag of the catenary varies according to the length of the span between the posts,

and consequently droppers of different lengths are used to meet the requirements of various cases. In erecting the overhead lines a special coach is employed, and the contact and catenary wire are unwound from their drums simultaneously. The

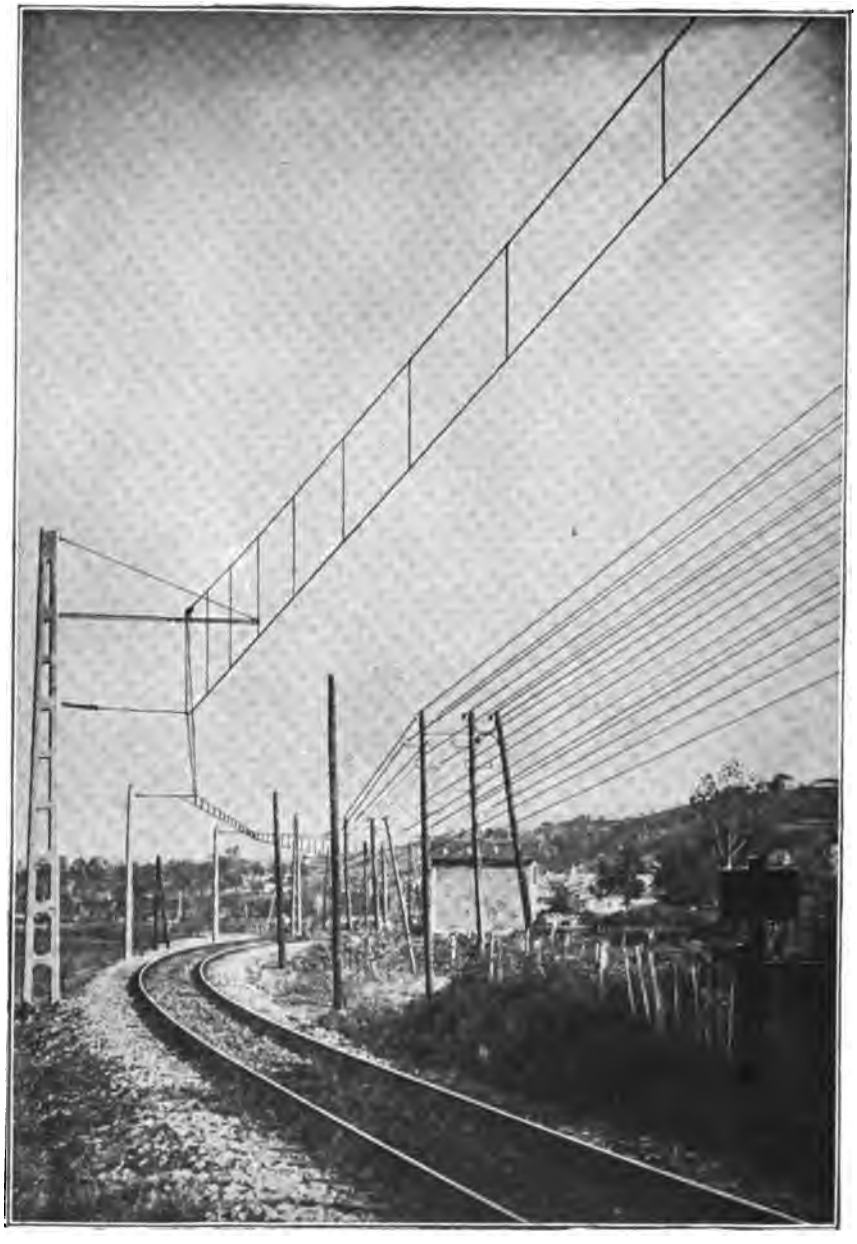


FIG. 60.—Pull-off Post on a Curve.

tensions of the two wires are also adjusted at the same time, this, it is claimed, being a great advantage. The method which this firm adopts for dividing the lines into sections is of interest. An illustration of one of the section posts on the Midi Railway is given in Fig. 59. At the top of these posts there are two lightning arresters of the horn type and an oil break switch for cutting out the sections.

This switch is capable of opening the circuit when the full load current is passing. When the switch is opened the lines are earthed in the usual manner. The switch is operated from the small box to be seen at the foot of the post, a rod connecting the switch at the top of the post with the handle in the box. A dial is provided which shows whether the switch is opened or closed. A liquid resistance and reactance coil are used in conjunction with the lightning arresters.

The type of section insulator used with this firm's single-phase equipment is shown in the drawing, Fig. 62, and also on each side of the sectioning post. It will be understood that tightening gear is also fitted to this post. It is scarcely necessary to describe the section insulator in detail, because the drawing, Fig. 62, is self-explanatory. It will, of course, be understood that the ends of the contact wires are brought close together; but, as will be gathered from the drawing, they are separated by a short air gap in a horizontal plane.

Two other views of this firm's overhead equipment as used on the Midi Railway are given in Figs. 63 and 64. One shows the pull-off posts on a curve, whilst the other two show the wires supported by metal structures. It will be noted that in one instance the overhead equipment is totally different to that described, this being the Paul system of overhead construction. The drawing, Fig. 65, shows the method of erecting dead sections under bridges on the Midi Railway. The drawing is also self-explanatory. Fig. 66 shows the arrangement of the overhead lines on the Midi Railway, where the span between the supports is 100 m., the suspension in this case being of the rigid type. The catenary cable and contact wire are tightened at the post on the right. Further, it will be seen that staying posts, to prevent the wires swinging sideways or for pulling the wires so as to make them conform with the curves of the rails, are erected between the two main supporting posts.

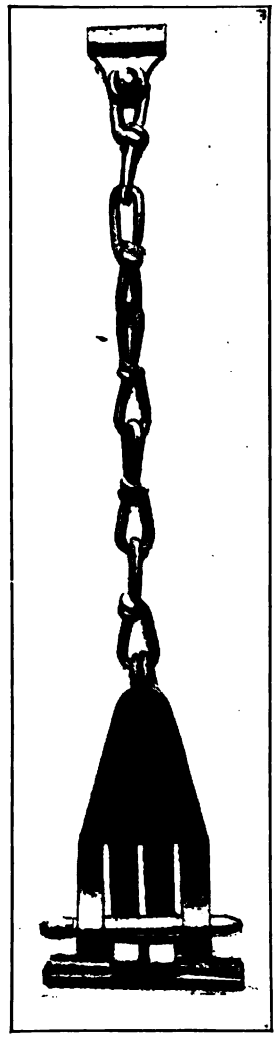


FIG. 61.—Flexible Dropper and Clip.

An interesting scheme has been devised by this firm for automatically energising and de-energising sections of the overhead lines which are considered dangerous, that is to say, wires which pass over level crossings, under bridges, and so forth. The system is used on the Italian State Railways, where the lines in some of the stations are only made alive on the approach of a train. These railways are electrified on the three-phase system, and there are, of course, two overhead wires over each track. The scheme is also being used on the Midi Railway. Referring to the drawing, Fig. 69, the section of the line which is controlled by the automatic equipment is that extending between the points S and S^1, and it will be gathered that this portion

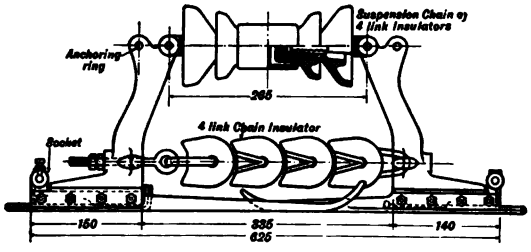


FIG. 62.—Section Insulator.

of the line is not in direct connection with the main overhead line, for there is a gap at S and S^1. In order to complete the circuit, however, when the dangerous section is dead, a by-pass wire $\alpha\ \beta$ is provided, so that under all conditions

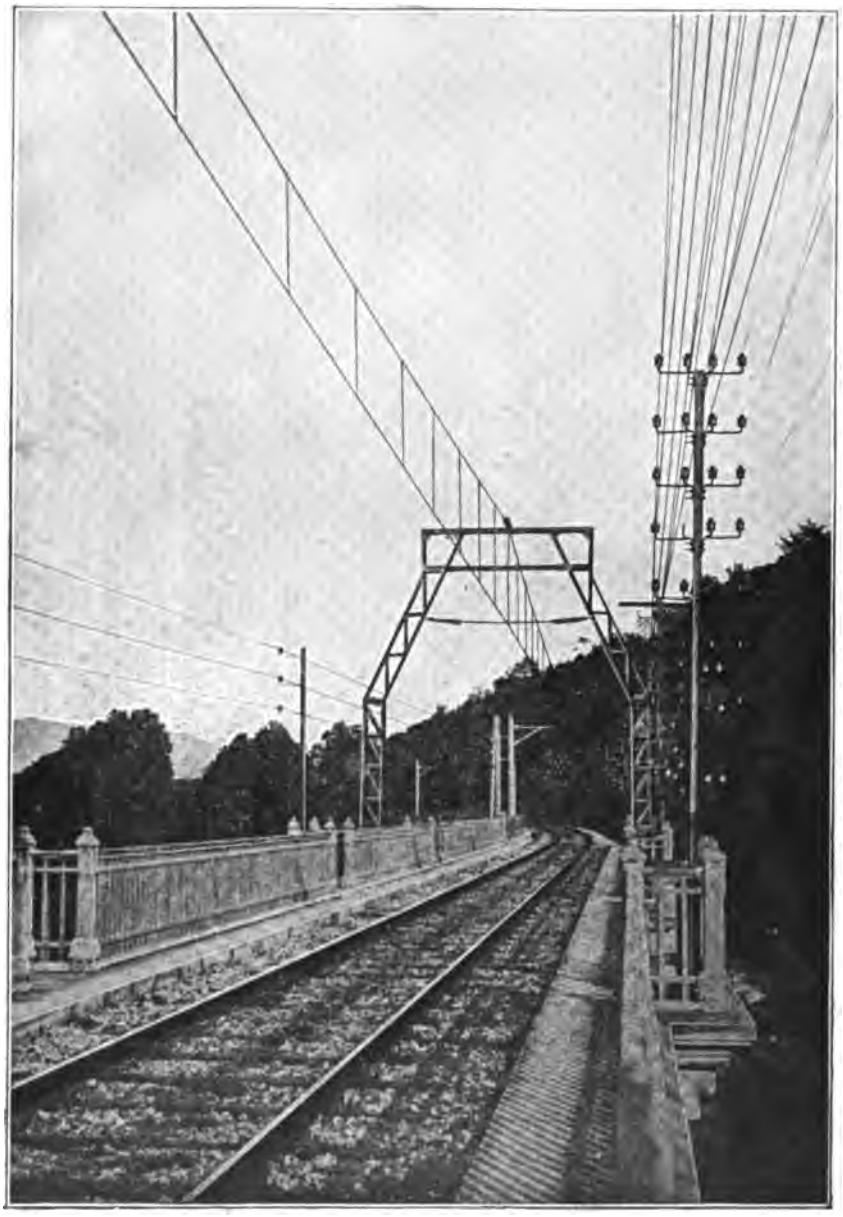


FIG. 63.—Lattice Construction.

current can be supplied to the trains on either side of the section S and S^1. This by-pass can obviously take the form of an underground cable or an aerial wire. The latter would be erected in a position where it would be perfectly safe. For example, in the case of a level crossing it might be erected at a height much greater than that of the overhead contact lines, and, moreover, a guard net could be used

to ensure safety in the event of the wire breaking and falling. Most probably, however, it would be more convenient to use an underground cable. The section S S^1 is switched in and out of circuit by means of an interrupter or switch J, which

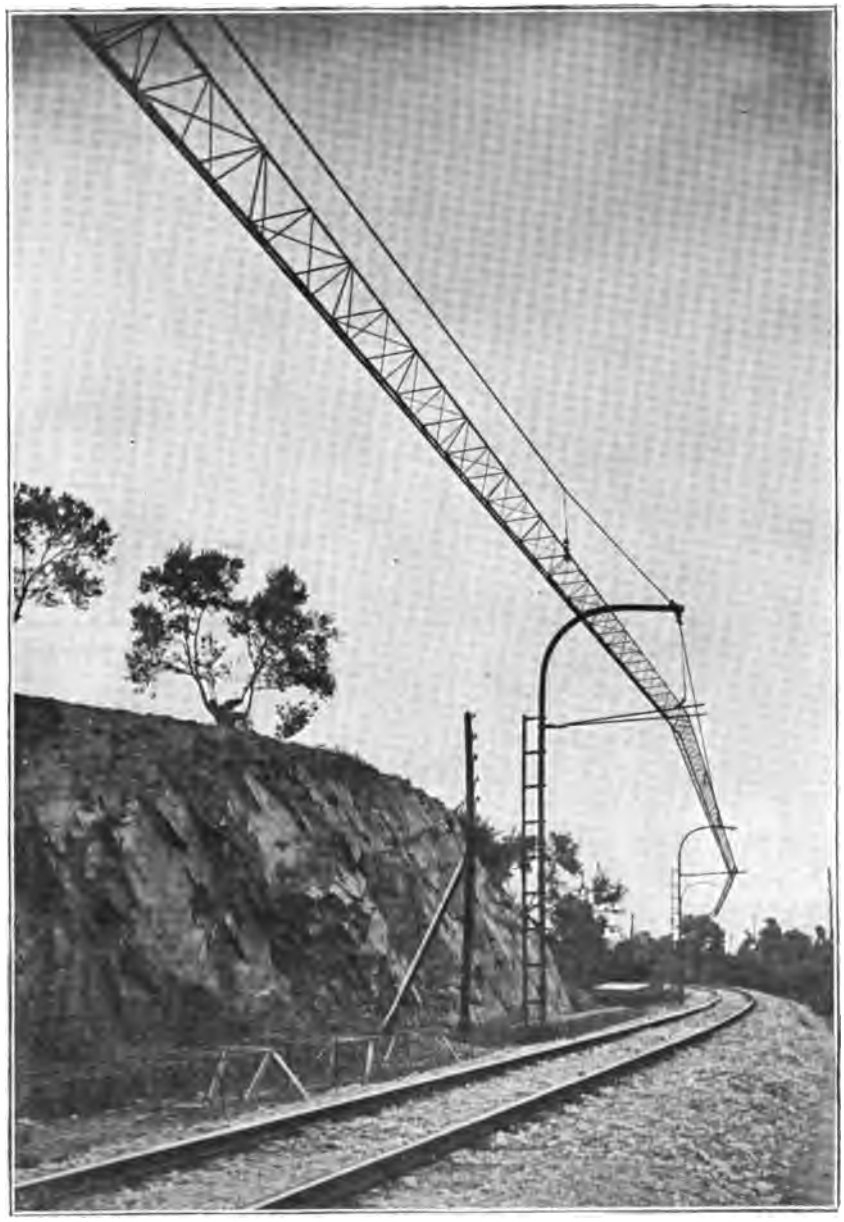


FIG. 64.—The Paul System of Overhead Construction.

is controlled by the mechanism enclosed in the case A, the controlling gear being connected to two contacts P and P^1 placed just above the contact wire. Therefore, when the train passes these contacts the bow lifts the wire and current passes into the windings of the electromagnetic apparatus which actuates the switch J. The contacts P and P^1 are placed about 15 m. away from the ends of the section S and

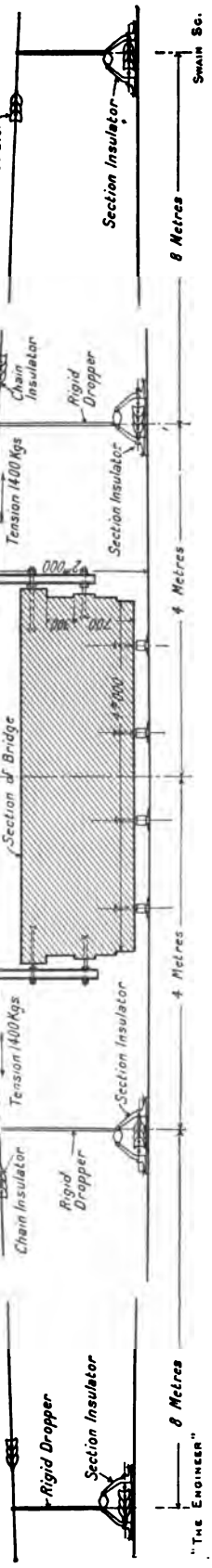


FIG. 65.—Dead Section under Bridge.

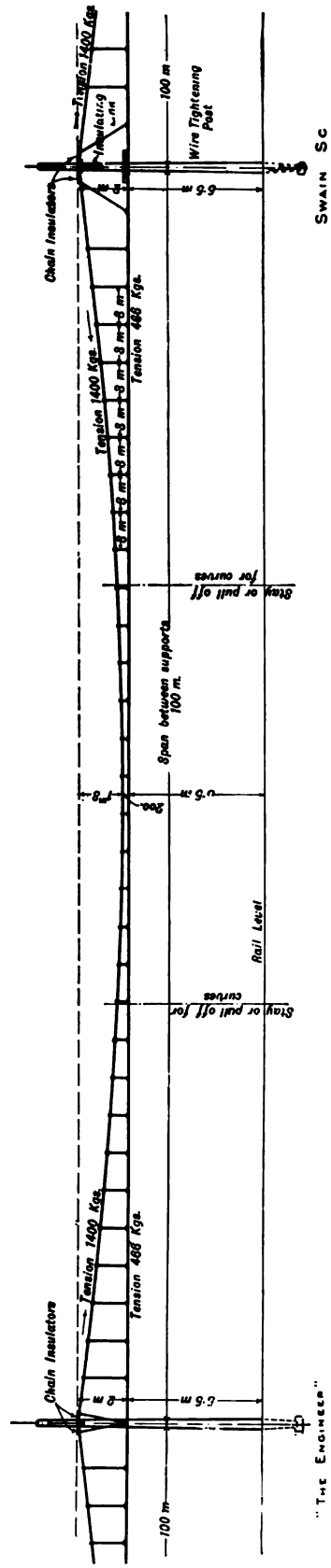


FIG. 66.—Overhead Line on Midi Railway, 100-m. Span.

S^1. Two lamps, F F, light up when the dangerous section is energised, and not only indicate that this section has been energised, but also act as signals and show the driver of the next train that he must not proceed until the road is clear. When a train is running into the dangerous section and the auxiliary circuit is closed at the point P^1, a small current flows by way of the conductor 3 into the primary of the small transformer T^1, which is situated in the bottom of the case I which contains the oil switch. The secondary of this transformer is connected to the solenoid *b*. When this solenoid is energised it disengages a catch and allows the weight P to fall. and in so doing it actuates the lever L and closes the switch J in the case I. When the dangerous section is long—as, for example, a section crossing villages or a section in a long tunnel—it may be divided into several parts, each part being controlled by an apparatus, as shown in the diagram. The two lamps F F are connected across the secondary winding of the transformer T, and consequently they light up when the dangerous section is energised. The small motor *m* is also connected across the secondary of the transformer T, and when the dangerous section is alive

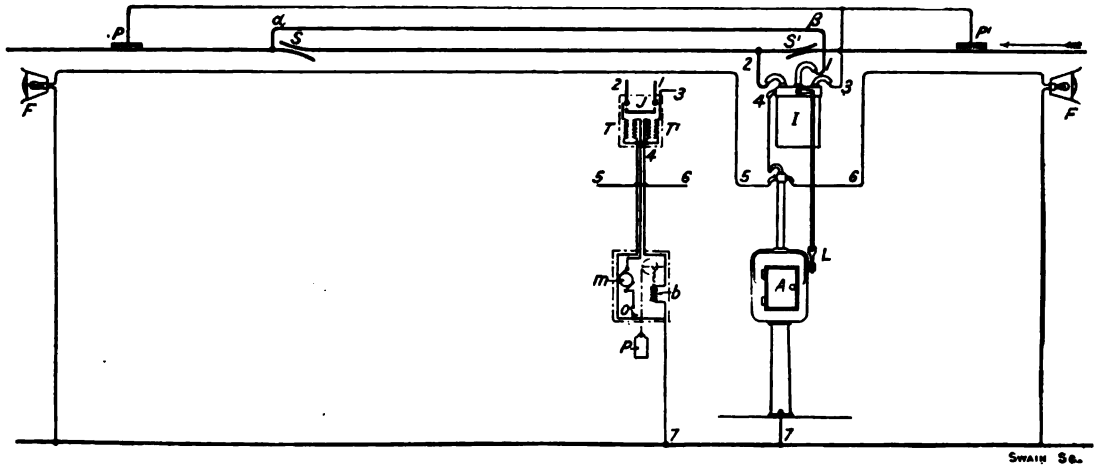


FIG. 67.—Connections for Automatic Control Gear.

this motor is set into operation and winds up the weight P. When the weight has been lifted to the desired height the small switch O is opened and the motor stops. When the train or locomotive leaves the dangerous section and the bow passes under the contact P there is another rush of current through the bobbin *b*, when the lever L makes a second half turn and the switch J is opened. The current is consequently switched off from the dangerous section and the lights F F are extinguished. From what has been said it will be gathered that the controlling apparatus is now set ready for energising the dead section again as soon as the bow of a locomotive or motor coach reaches the point P^1, and as soon as the vehicle has passed over the dangerous section the switch S will open as before. In the event of two trains entering the dead section, so that the bows of both trains are in contact with the wire S and S^1 at the same time, it is evident that the second bow, in passing the point P^1, will have the effect of making the dangerous line dead, and under these circumstances one of the drivers would have to leave his train and close the switch J by hand. It is also clear that the current might fail at the power station just before the train reached the point P^1, when it would coast into the dangerous section and remain there. Evidently when the supply is renewed the section S S^1 would still remain dead and the

driver would then have to close the switch as before. If, however, the current failed whilst the train was travelling over the dangerous section of the line, it would simply be necessary for the driver to put the handle of the controller into the " off " position and wait until the supply was restored. But if the train was allowed to coast all the way through the section whilst the current was off, the line S S^1 might become energised just as the bow reaches the point P, and then the dangerous section would probably remain energised after the train had passed; but under these conditions the fact would be indicated by the lighting of the lamps F F, and the current could be switched off by the driver of the train or some other authorised person. Therefore, although under certain circumstances, which are not often likely to arise, the dangerous section will not be energised automatically, the provision of the lamps F F enables the staff to see what is wrong and to correct matters accordingly. The London agents for Vedovelli, Priestley et Cie. are Laing, Wharton, Limited, of 7, Great Newport-street, W.C.

The locomotives submitted by the various manufacturing firms had to conform with the following conditions. The engines to be capable of starting and hauling on any part of the line, shown in Fig. 68, a train weighing 400 tons without the locomotive. With a load on the train of 280 tons the maximum speed should not be less than 40 km. per hour, and with a load of 100 tons 60 km. per hour.

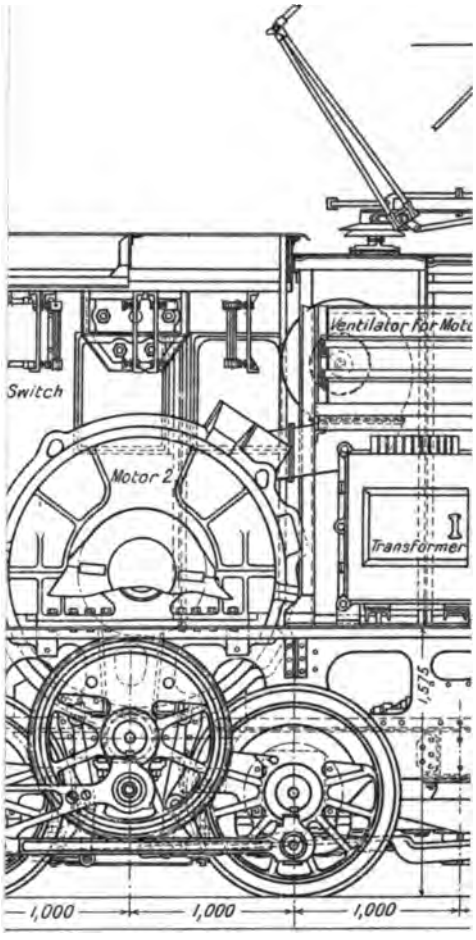
In running from Villefranche to Ille the motors have to be capable of sending current back into the line and of being regulated at will, so that half the normal speed can be obtained if desired. Moreover, it was specified that when operating at the normal voltage each of the motors should give 600 h.p. without the temperature rising above 75° C. after a period of six hours. They were also to give 25 per cent. overload for one hour without the temperature exceeding the above limit. The motors were to be capable of carrying the current corresponding to the following tractive efforts :—

12,500 kilos. at the start.
8,000 kilos. at a speed of 45 km. per hour.
4,200 kilos. at a speed of 60 km. per hour.

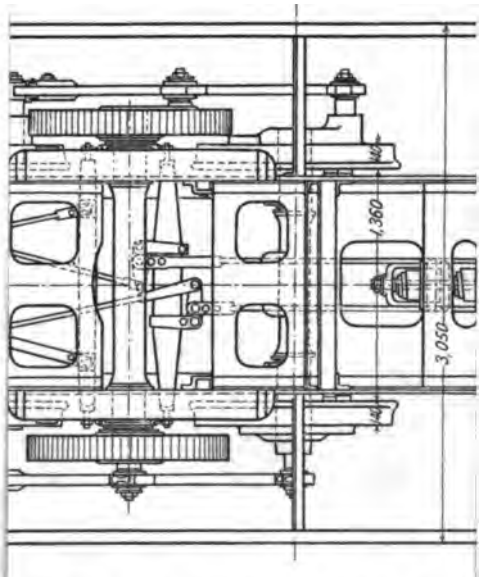
Rigid restrictions were also imposed with regard to commutation. The weight of the locomotives was limited to about 80 tons, with a maximum of 18 tons per axle and an adhesive weight of 54 tons. The following table gives particulars of three locomotives accepted :—

	Locomotive supplied by the Compagnie Thomson-Houston	Locomotive supplied by the Société Westinghouse.	Locomotive supplied by the Construction Electriques du Nord et de l'Est (Jeumont).
Total weight, tons	88	81	80
,, length, m.	13·75	11·37	15·27
,, wheel base, m. ..	9·6	8·8	10·6
Diameter of driving wheels..	1·31	1·2	1·4
Number of motors	2	2	3
H.p. of each motor* ..	600	600	500
Method of drive	Coupling rods driving two intermediate shafts.	Gearing and intermediate rods.	Gearing.

* In constant service.



al Plan of Chassis.



0.—1,200 h.p. Westinghouse Single-Phase L

The French Westinghouse Company's locomotive as built for the Midi Railway is shown in Fig. 69, and Fig. 70 is a drawing of the engine. The pinions on the two motor shafts mesh with two gear wheels mounted on intermediate shafts, and the power is then transmitted to the driving wheels by a yoke and side rods in the manner shown. The locomotive is divided into two distinct portions, and a separate transformer is employed for each motor. The total length, measured over the buffers, is 11·37 m., the total wheel base 8 m., and the rigid wheel base 4 m. The engine has a total weight of 81 tons, the mechanical portion accounting for 38 tons and the electrical equipment 43 tons. Motors and gearing weigh 27 tons, transformers and preventive coils 9·5 tons, the multiple control mechanism 3·5 tons, compressors 1 ton, ventilators, current collectors, and accessories 2 tons. The motors are of the forced ventilated type. They are series-compensated machines. Fig. 71 shows a motor complete, Fig. 72 the field system with the armature removed, and Fig. 73 an armature. The ratio of the gearing is 45 : 74. Like the motors, the transformers are of the forced ventilated type. The Westinghouse Company's electric-pneumatic system of control is used.

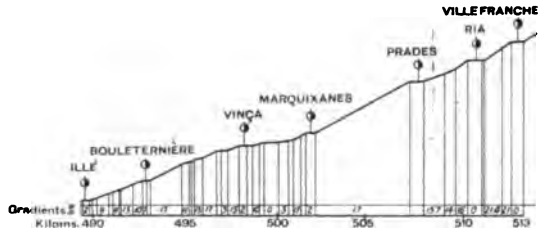


FIG. 68.—Profile of Line from Villefranche to Ille.

The contactors are closed with compressed air and opened by springs. The

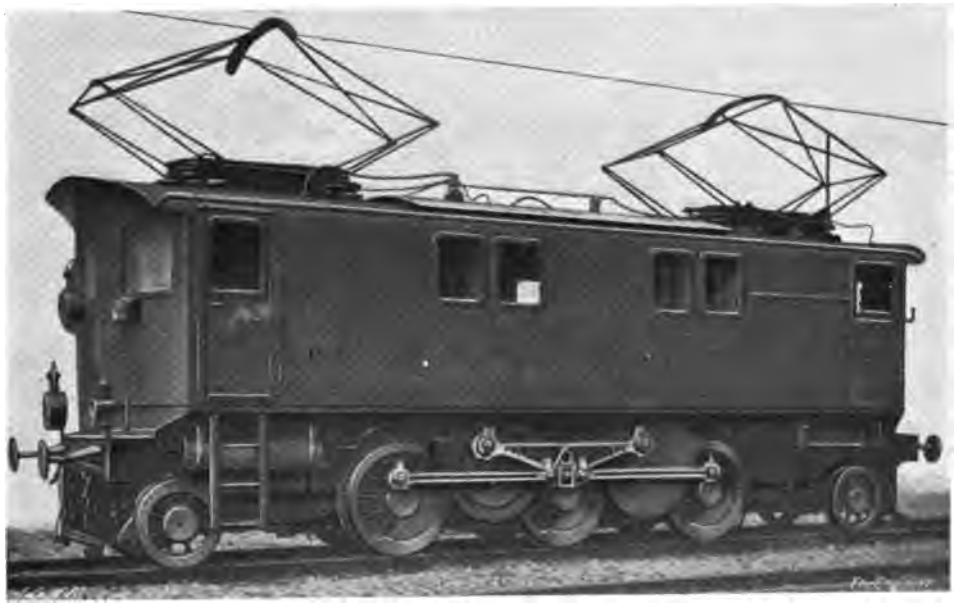


FIG. 69.—1,200 h.p. Westinghouse Single-Phase Locomotive.

electro-pneumatic valves are supplied with current from the transformers at a pressure of 65 volts. The electrical connections of this locomotive are simple, as can be understood from the diagram of connections, Fig. 74. Here the motor switches are marked A, the transformer switches B, the field windings C, the motor armatures M^1, M^2, and the transformers T_1 and T_2. The sequence in which the switches are closed is shown in the diagram, Fig. 75. The maximum pressure applied to the terminals of the

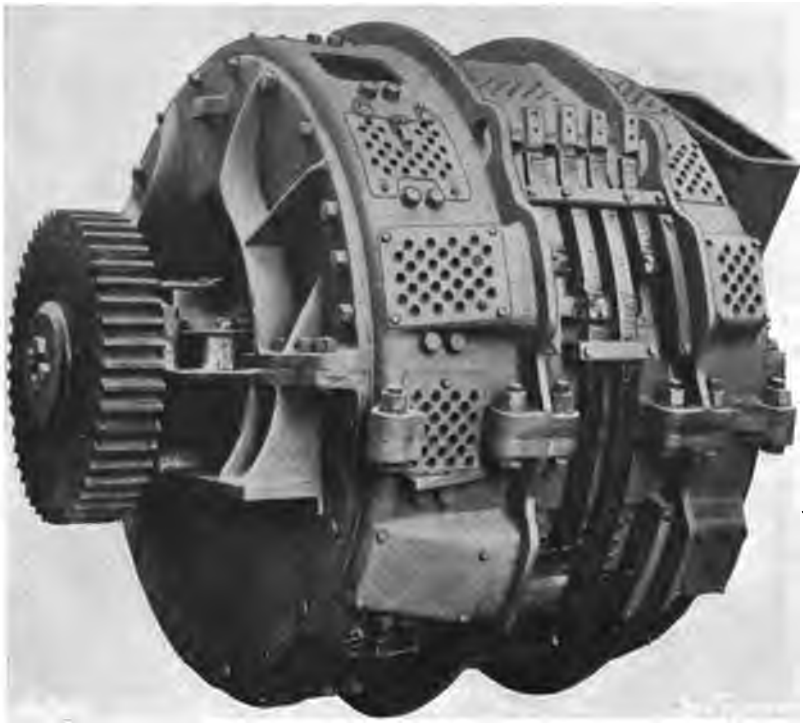


FIG. 71.—600 h.p. Single-Phase Motor.

FIG. 72.—Motor with Armature Removed.

motors is 420 volts. It has been stated that the specification for these locomotives demanded that when the engine is running on a down gradient it should be capable of returning current to the line. In the first instance, the Westinghouse locomotive was designed in accordance with these requirements. The braking action was obtained by separately exciting one of the motors, the excitation of the second being obtained

FIG. 73.—Armature of 600 h.p. Motor.

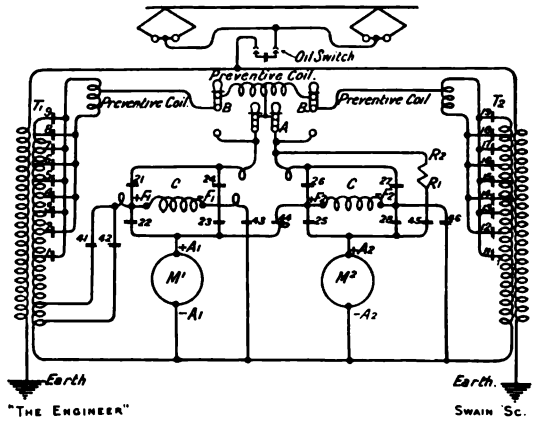


FIG. 74.—Connections for Westinghouse Locomotive.

from the armature of the first. Apparently the scheme introduced a great deal of complication, and it has now been abandoned. Another system of electric braking, however, has been introduced.

Instead of returning the current to the line, resistances are connected to the transformers. This scheme has proved quite satisfactory so far as braking is concerned, although, of course, it is not a regenerating system. During the trials it was found possible to brake a 100-ton train on a 1·7 per cent. gradient, and to regulate the speed between 62 and 10 km. per hour. With a 280-ton train it was possible to reduce the speed from 42 to 14 km. with the use of the resistances. This system of braking has been found to answer the requirements. The regenerating scheme not only complicated the electrical equipment, but it also demanded a great deal of care and attention on the part of the driver. The builders of this locomotive point out that, in order for the regeneration of current to be of advantage, it is necessary for at least two locomotives to be in use at the same time, otherwise the regenerated current is sent back to the power station, where it may prove a source of trouble. On the Giovi line, near Genoa, for example, where three-phase current is used on the locomotives, a special liquid resistance has been put down in the power house for the purpose of absorbing the current sent back to the generating station when the regenerated energy exceeds the demand.

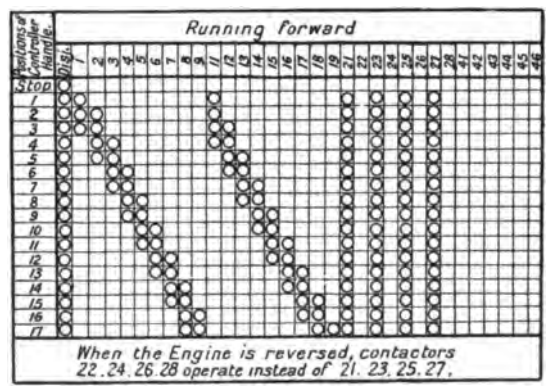

Positions of Controller Handle.
Running forward
Stop
When the Engine is reversed, contactors 22.24.26.28 operate instead of 21. 23. 25. 27.

FIG. 75.—Diagram showing Order of Closing Contactors.

The following table gives the results of some trials which were carried out with the French Westinghouse Company's single-phase locomotive on an incline of 1·7 per cent. The weight of the train hauled was 280 tons, and the approximate tractive effort 6,100 kilos. :—

Speed in km. per hour	42
Power (draw-bar)	950 h.p.
Volts	11,000
Amperes	100
K.V.A.	1,100
Kilowatts	970
Cos θ	·88
Efficiency	72·4

The efficiency is calculated from the power available for hauling and that measured by the electrical instruments in the sub-station.

Orders have also been placed for thirty Westinghouse motor coaches, which will have two bogies, each fitted with a pair of motors. A drawing of one of these motor coaches is given in Fig. 76. B_2 is the compressor case, I high tension switch, R ventilated resistances, T main transformer. The total length is 19 m. There will be

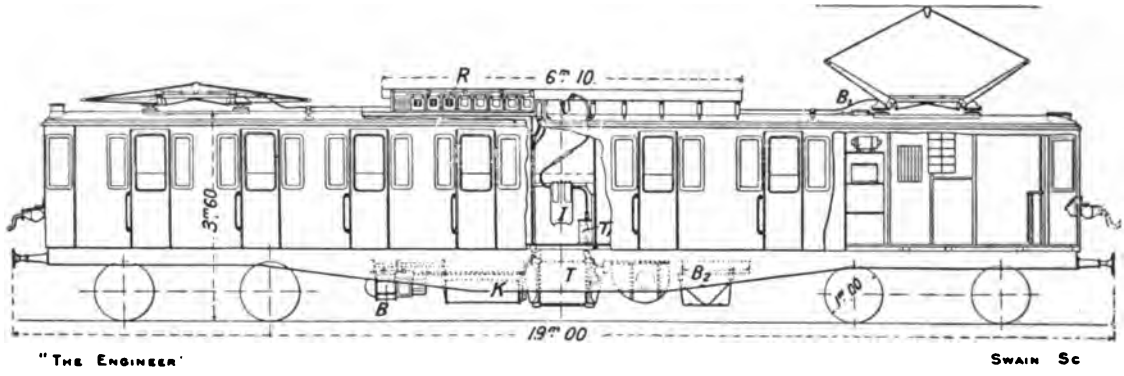


Fig. 76.—Motor Coach for Midi Railway.

four second-class compartments, each containing thirty-two seats ; two first-class compartments having twelve seats, one lavatory, a luggage compartment, and two drivers' compartments.

The locomotive constructed by the French Thomson-Houston Company was built to conform with the conditions already given. Apparently, much consideration was paid to the question of how the power developed by the motors should be transmitted to the driving wheels. This seems to be a question which some firms have had difficulty in settling. Opinions differ as to whether the motors should be of the geared type or whether they should be built for a comparatively slow speed and drive the wheels by means of rods. After much experimental work the French Thomson-Houston Company has come to the conclusion that the latter scheme is preferable. Accordingly the locomotive which has been built for the Midi Railway is fitted with two fairly slow speed motors having cranks at each end of their shafts. Connecting rods coupled to these cranks transmit the power to the intermediate shafts placed in the same plane as the wheel axles, and from these intermediate shafts the power is transmitted to the six driving wheels by horizontal side rods. Fig. 77 shows the complete locomotive. The connecting-rods are inclined at the greatest possible angle, the motors being placed close to the centre of the locomotive. Fig. 78 shows

the motors erected on the test plate, whilst Fig. 79 shows them in the locomotive. Bare copper conductors are used for conducting the low tension current to the motors.

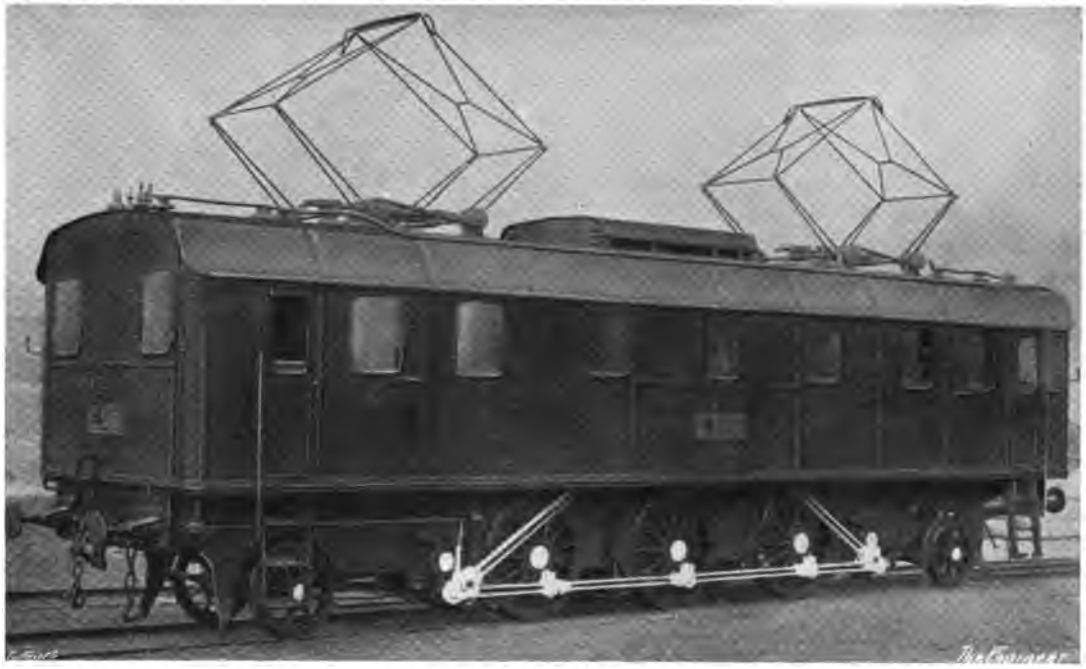


FIG. 77.—1,200 h.p. Thomson-Houston Single-Phase Locomotive.

There is only one transformer on this locomotive. It is placed near one of the driver's compartments, as shown in Fig. 80. Owing to the manner in which the motors,

FIG. 78.—Motors Mounted on Test Bed.

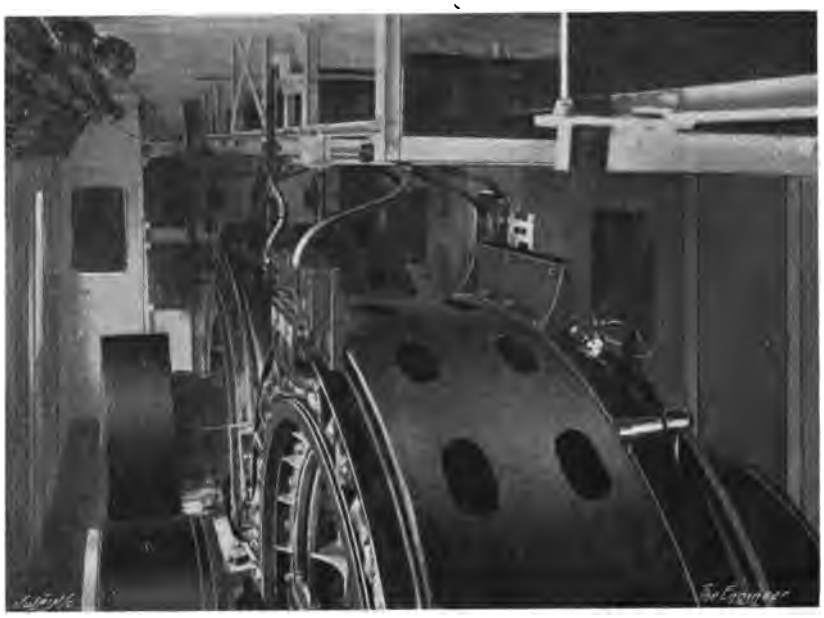


FIG. 79.—Motors Mounted in the Locomotive.

etc., have been arranged the height of the centre of gravity of the engine is comparable with that of a good steam ocomotive.

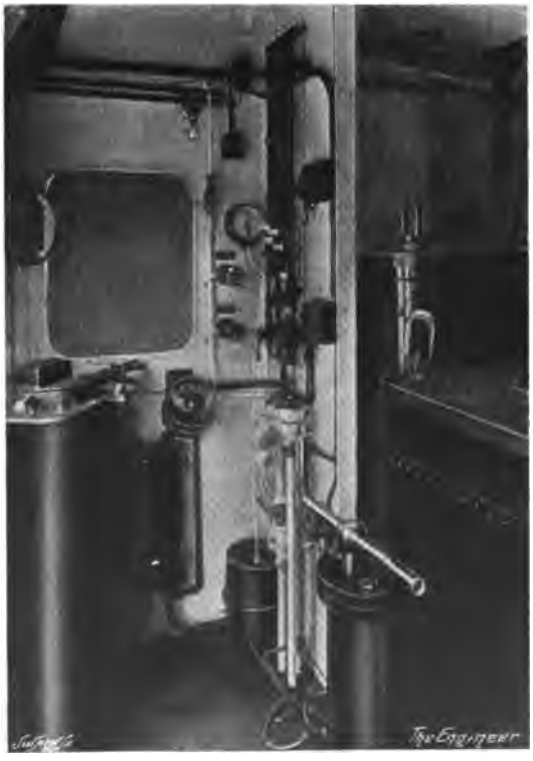


FIG. 80.—Driver's Compartment of Thomson-Houston Locomotive.

The motors used on this locomotive are started as series repulsion machines. In designing the motors the objects aimed at have been to obtain a good starting torque and satisfactory commutation. To secure the latter the motors have been provided with a large number of poles, for it is an established fact that the quality of commutation is dependent on the magnitude of the electromotive force induced in the short-circuited armature turns. This electromotive force is governed by the magnitude of the field flux. By using a large number of poles the flux per pole can be reduced, with a corresponding reduction in the electromotive force induced in the short-circuited coils of the armature. When starting the brushes are short-circuited and current is supplied to the stator terminals. After the motor has attained synchronous speed the armature is connected in series with the field windings. A voltage is also impressed on the compensating winding which produces a commutating flux. This voltage is obtained from the secondary of the

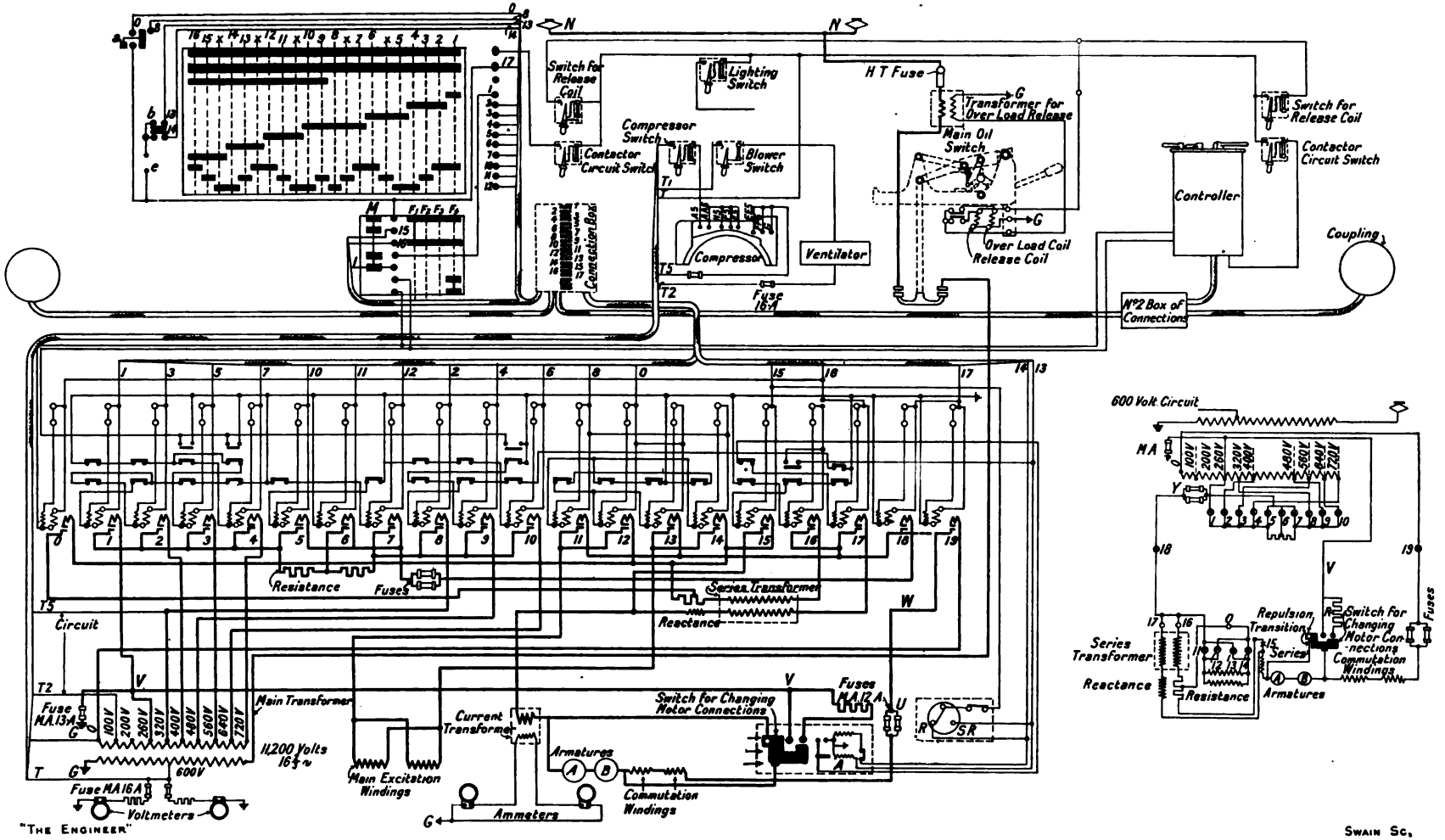


Fig. 81.—Connections for Thomson-Houston Locomotive.

main transformer. The motors each have twenty poles; consequently the synchronous speed when working as a repulsion machine is 100 revolutions per minute—periodicity $16\frac{2}{3}$. This speed corresponds to 25 km. per hour. When the armatures are connected in series with the field windings the maximum speed of the locomotive is 78 km. per hour, about three times the value obtained when the motors are running at synchronous speed. The following table gives the leading dimensions of this locomotive :—

	Metres.
Diameter of driving wheels	1·310
Diameter of pony wheels	·850
Total wheel base	9·6
Length over buffers	13·75

Current is collected from the overhead wire by means of two pantograph collectors. These are held in contact with the overhead line by means of springs and lowered with compressed air. Each motor is designed for developing 600 h.p. continuously and 750 h.p. for one hour. Fig. 81 is a diagram of connections for the Thomson-Houston Company's locomotive, a simplified diagram being given in the right-hand corner. In the main diagram high-pressure and heavy current circuits are represented by thick lines. The high-tension circuit from the current collectors N N to the main transformer in the lower left-hand corner can easily be traced. A fuse, as shown in Fig. 82, is inserted in this circuit. Near to this fuse (200 amperes) there is the main oil switch. Overload and release coils are fitted to this switch. A tapping taken off from the primary of the transformer gives a pressure of 600 volts. Current at this pressure is used for the lighting circuit, the contactor control circuit, and the oil switch release circuits. The switches for these three circuits are marked on the diagram. It will be understood that the main oil switch is fitted with remote control, so that it can be opened electrically from the driver's platform.

FIG. 82.—High Tension Fuse.

Since the high-tension switch is fitted with an overload trip coil and since a fuse is interposed in front of this switch, it is evident that the motors are well protected, and there is little fear of the electrical equipment being damaged by overloads. The main oil switch shown in Fig. 83 can either be closed by hand or by compressed air. A diagram showing the arrangement of the compressed air pipes is shown in Fig. 84. This will be referred to again presently. The main transformer is of the air-cooled type and is designed to withstand four times the normal working pressure. Its secondary has seven main tappings giving pressures ranging from 260 to 720 volts. A circuit working at a pressure of 100 volts supplies current to the motor driving the blower. Another circuit worked at 320 volts supplies current to the compressor motor. The 600-volt circuit, as already explained, supplies current for the control magnets of the contactors. The wiring diagram shows that the secondary circuits are controlled by means of twenty contactors. Views of one of these contactors are given in Figs. 85 and 86. The small diagram in the right-hand corner of Fig. 81 assists in following the change in connections for starting, reversing, braking, and running. Contactors 11, 12, 13, and 14 are brought into use for reversing the direction of running. They reverse the direction of current in the field winding with respect to that in the armatures at any given instant. Contactors 11 and 13 are

closed for one direction of running and contactors 12 and 14 for the opposite direction. The reversing contactors cannot be actuated whilst the motors are being supplied with current.

Although the builders of the locomotive previously described abandoned the idea of employing a regenerating system of braking, the engine now under consideration is designed for returning current to the line. One difficulty attending the scheme is that of preventing the motors generating continuous current. If a series motor is connected to the secondary winding of a transformer it is clear that the winding of the latter, together with the armature, forms a closed circuit. If, therefore, the motor acts as a generator there is nothing to hinder it producing a continuous current, the magnitude of this being only limited by the ohmic resistance of the circuit. On the locomotive built by the Thomson-Houston Co. a series transformer is interposed in the braking circuit, as shown in the small diagram in the right-hand corner of Fig. 81. This transformer is put into circuit by the contactors 16 and 17, which are closed during the braking period, contactor 15 being opened. When the

FIG. 83.—Main Oil Switch.

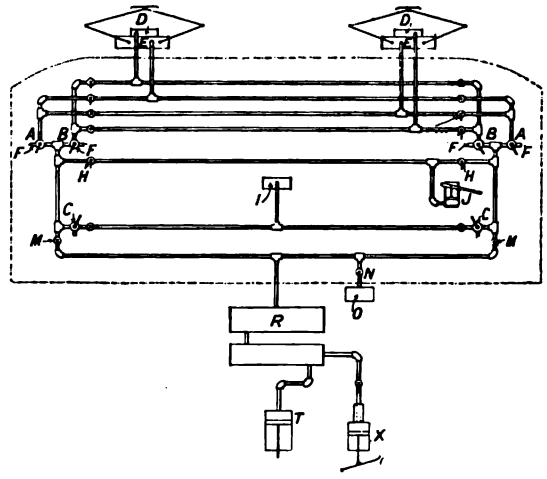


FIG. 84.—Arrangement of Compressed Air Pipes.

locomotive is taking in current, on the other hand, contactor 15 is closed and 16 and 17 are open. It has been found that the regenerated energy on a given gradient may be as much as 40 to 45 per cent. of the power absorbed on the ascent of the gradient. The switch for giving series repulsion and series connections is to be seen in the small diagram on the right of Fig. 81 and also in the main diagram.

In order to prevent interrupting the circuit as the changes in the connections are made, resistances are used as shown under the contactors 5 and 6. These are connected to the contactors 5, 6, and 7 in the manner indicated. An illustration of the resistances is given in Fig. 87. Since a failure in the 260-volt supply derived from the point V of the transformer might lead to sparking at the brushes, it was considered inadvisable to include a fuse in this circuit. Similarly an interruption on the circuit W might also lead to very unsatisfactory working. Accordingly,

contactor 19 is fitted with an interlocking device, so that when it opens it carries contactor 18 with it, and *vice versâ*. Obviously, the blowing of the fuses U might also be the means of producing sparking at the brushes; therefore, these fuses have been made exceptionally heavy, so that they will only blow in the event of a bad short

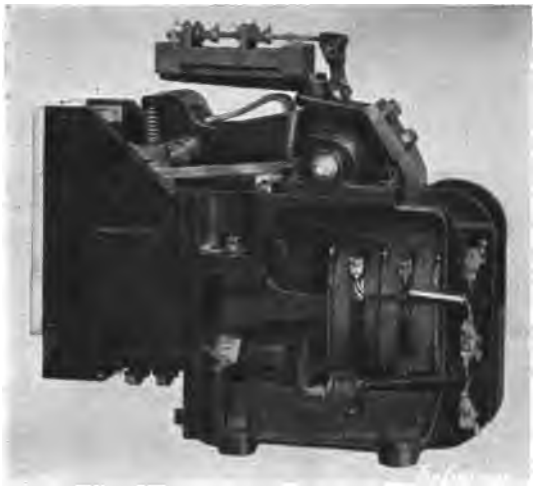


FIG. 85.—3,000 Ampere Contactor.

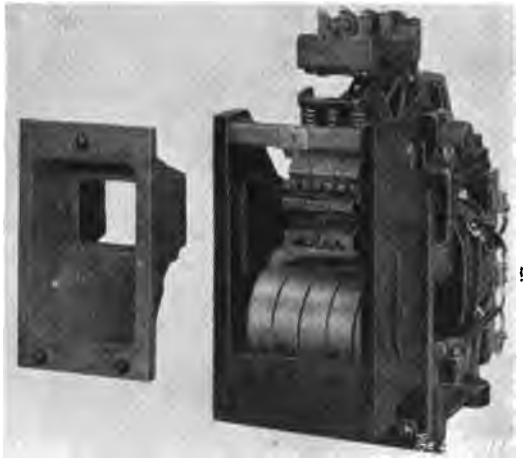


FIG. 86.—3,000 Ampere Contactor.

circuit. The fuses in series with contactor 7 serve to break the circuit when the motors are overloaded. Should a breakdown in the insulation occur between the windings of one of the motors and the frame, the fuse MA to be seen at the lower left-hand corner of the diagram is brought into action. This, it will be observed, is connected between the 260-volt tapping and earth. The capacity of this fuse is small as compared with that of the other fuses. Its main object is to avoid accidents arising from a static charge.

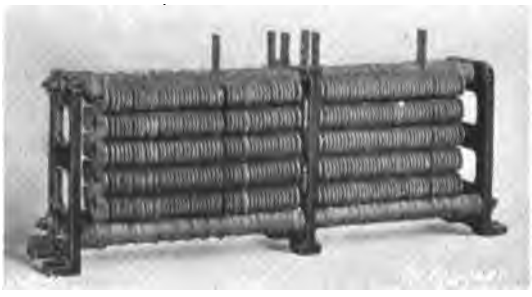


FIG. 87.—Resistance Unit.

Let us now return to the switch, which is used for changing the connections of the motors, and which is shown to the best advantage in the small diagram in the right-hand lower corner of Fig. 81. This switch, it should be explained, is operated by compressed air from either of the controlling platforms. It either short-circuits the armatures of the two motors or joins up the wire V to the commutation windings. A resistance R is used in conjunction with this switch, which only remains in circuit for a short period. All other changes in the secondary connections are made by the contactors. The seven contactors 1, 2, 3, 4, 8, 9, and 10 are used for accelerating and reducing the speed of the locomotive. The three contactors 5, 6, and 7 control the resistances which serve to limit the current each time one of the secondary sections of the transformer is short circuited. These resistances lessen the variations of the current of the motor each time a secondary section of the transformer is brought into service. More tappings would be necessary in the absence of these resistances or their equivalent. Contactors 11 to 14 serve for reversing the direction of running

as explained. Contactors 18 and 19 are similar to the so-called principal contactors used on continuous current locomotives. Contactors 15, 16 and 17 are used for braking. Contactor 15 disconnects the main excitation winding from the armatures. Contactor 16 connects them to the braking circuit, that is, to the series transformer and resistance. Contactor 17 connects up the other winding of the transformer which is in series with a reactance coil. Finally, contactor O shunts one part of the resistance in the manner shown in the small right-hand diagram. It has been explained that the commutator switch which short-circuits the armatures, etc., at starting is actuated with compressed air. The electrically operated valve which admits air to the piston controlling this switch is indicated at A in the lower part of the large diagram.

Each controller, as shown in Fig. 88 and in detail in the top left-hand corner of Fig. 81, has three handles, the main controlling handle, the braking handle, and that used for reversing. There are also three separate cylinders. *a* is the cylinder for changing the direction of running. The contact device *b* is connected with the relay which actuates the valve of the compressed air cylinder of the commutator switch provided for the purpose of connecting up the motors for repulsion and series working. First of all this contact device gives the repulsion connection, but when the main controller handle is turned to the ninth position it opens automatically and causes the commutator switch to connect up the motors for series working. The contactors are capable of dealing with currents up to 3,000 amperes at pressures of from 450 to 800 volts. They are fitted with magnetic blow-out gear and renewable auxiliary contacts.

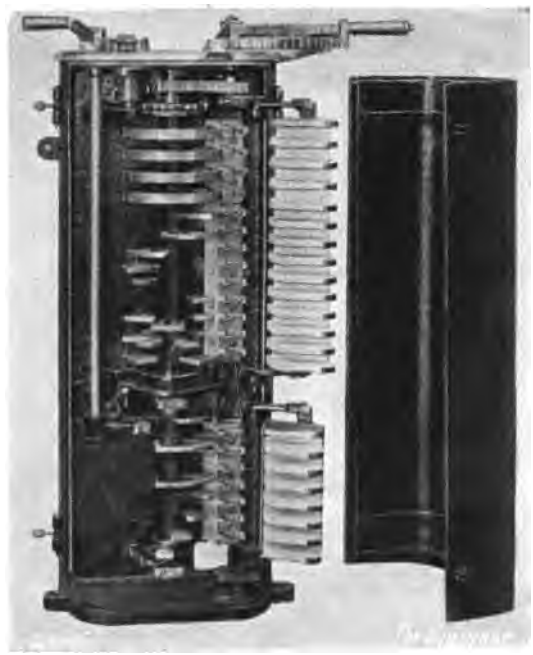


FIG. 88.—Controller.

Turning now to the diagram Fig. 84, compressed air is stored in the reservoir R. The compressor, which is indicated at T, is operated with a repulsion motor. The regulator which automatically starts and stops the compressor is shown at X. The compressed air pipes can be charged with the hand pump J. This is used in the event of the reservoir being empty and no current available. After the supply of compressed air has been obtained the various switches, etc., can be closed. The cocks MM are closed when the hand pump is used. The cylinder I controls the main oil switch. But when the hand pump is used the oil switch is usually closed by hand. In order to put one of the current collectors into contact with the line it is necessary to release the air in the corresponding cylinder D. To lower either of the collectors it is simply necessary to open the bolting clock previously closed and to send air into one of the cylinders E by turning the three-way cock from the escapement position to the position which enables air to pass into the cylinders. AB are the three-way cocks for controlling the current collectors. CC are the three-way cocks for closing the main oil switch from either end of the locomotive, FF are the escapement pipes, and N is the cock which admits air to the cylinder O which actuates the switch for

short-circuiting the armatures. The voltmeters in the drivers' compartments are connected to the secondary circuit, but are graduated to give the primary pressure, the scale extending to 14,000 volts.

The locomotive built for the Midi Railway by the Ateliers de Constructions

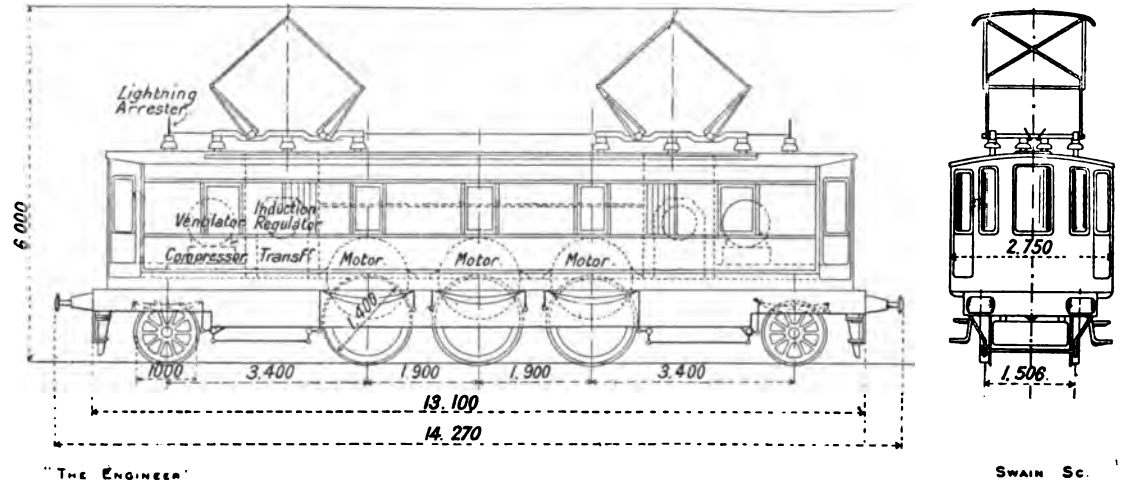


Fig. 89.—1,500 h.p. Single-Phase Locomotive.

Electriques du Nord et de l'Est possesses a number of interesting features and differs considerably from the other engines that have been described. It is of the 2–6–2 type, and is fitted with three 500 h.p. single-phase motors. The drawing, Fig. 89, gives the arrangement of the motors and other portions of the electrical equipment,

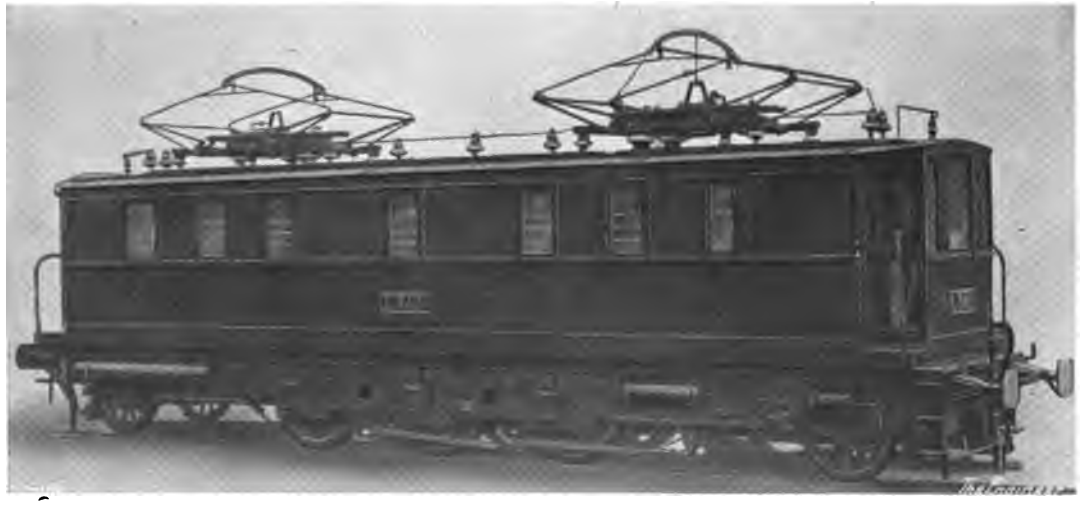


Fig. 90.—1,500 h.p. Single-Phase Locomotive.

while Fig. 90 shows the actual engine. There are no rods of any kind. Each motor is geared to a hollow spindle or quill, which surrounds the driving axle, the ratio of gearing being 1 to 2·72. The system of driving will be understood from Figs. 91, 92, and 93. The hollow spindle A is coupled to the driving wheels by means of an elastic

coupling. At each end of the hollow spindle there are arms B. The circular coupling piece G has four extensions. Two of these, TT, are free to turn and slide in the bronze shells C mounted in the arms B and two, T^1 in the shells C^1, held with a certain amount of play in the track wheel flange. This permits of a small amount of rotation of the hollow shaft around the driving axle and a certain inclination to its axis. The shells C^1 are designed so that they can slide parallel to the axle in their bearings P. It will therefore be seen that the couplings allow for side play. Moreover, the bearings P are held between springs R in the wheel flange. These springs prevent shock when the locomotive is started, and serve to damp out oscillations in the driving torque of the single-phase motors. The centre of gravity of this engine is 1·8 m. above the tops of the rails. The following are the leading dimensions :—

FIG. 91.—Driving Wheels and Coupling.

Gauge	1·435 m.
Length over buffers	14·27 m.
Height of body above rails	3·5 m.
Height with pantographs (max.)	6·5 m.
Height with pantographs (min.)	4·5 m.
Diameter of driving wheels	1·4 m.
Diameter of pony wheels	1 m.
Weight on each driving axle	18 tons
Total weight of locomotive	85·3 tons.

There are many things shown on the diagram of connections—Fig. 94—which call for detailed description before their functions can be understood, but it will perhaps

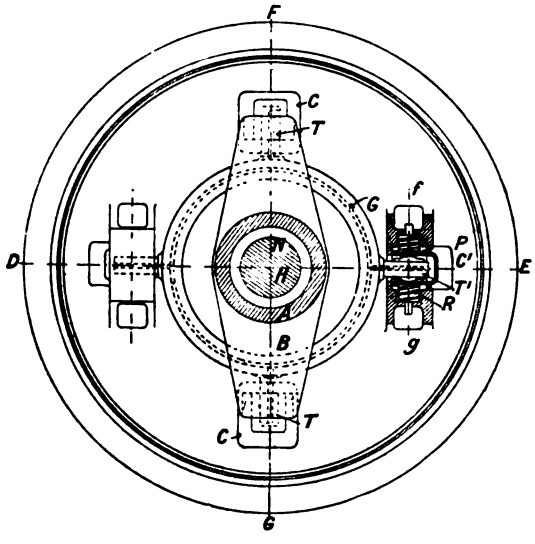


FIG. 92.—Flexible Coupling.

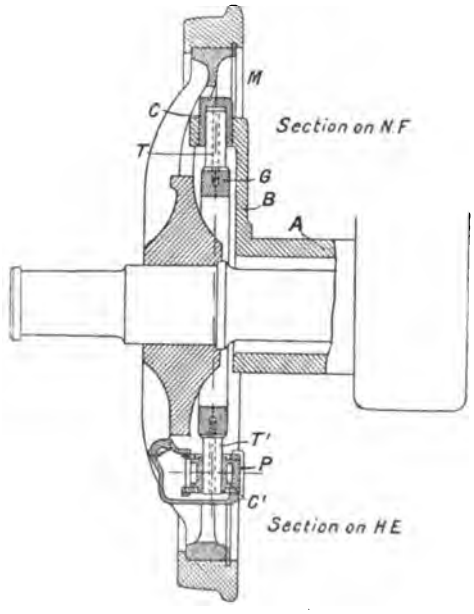


FIG. 93.—Section of Coupling.

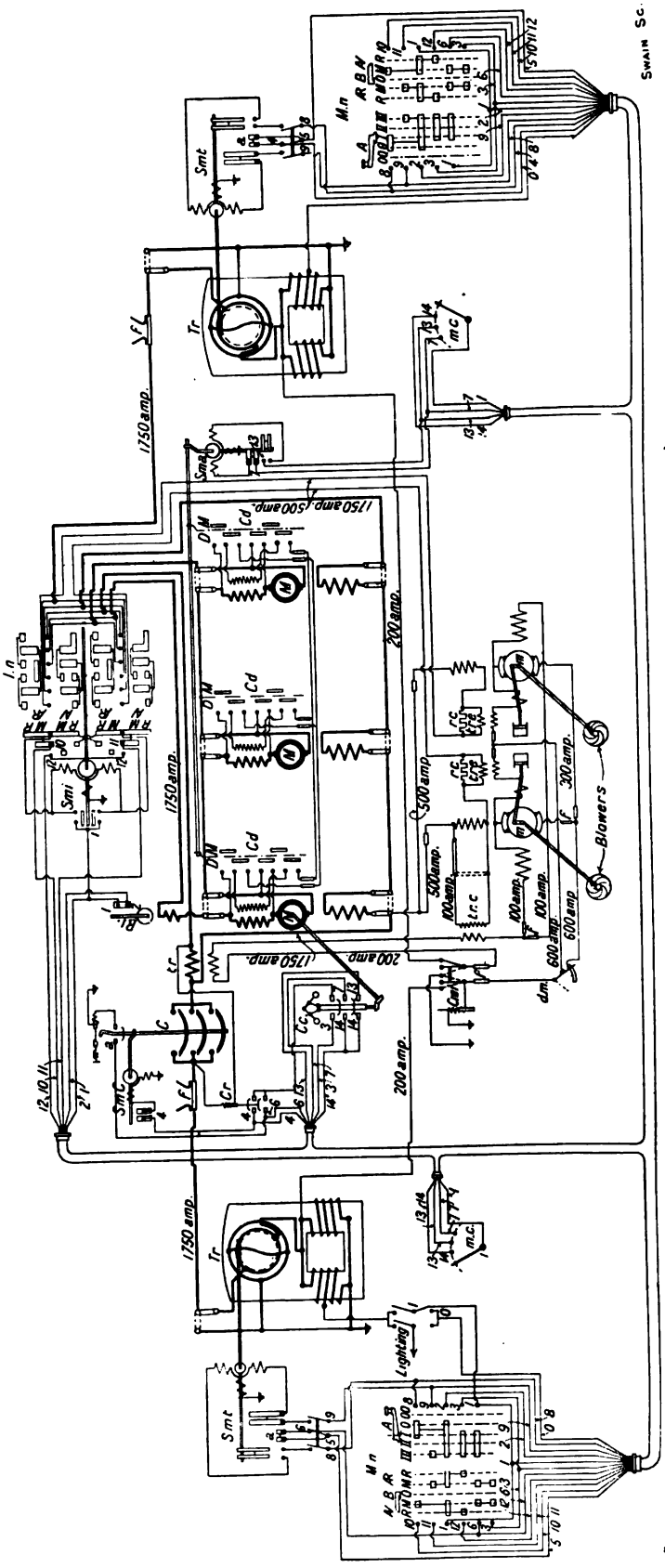


FIG. 94.—Diagram of Connections for 1,500 h.p. Single-Phase Locomotive.

be advisable to indicate what the various letters represent before proceeding further. T*r* main transformers ; M main motors ; *m* compressor and blower motors ; *tr* series transformer for regenerative control ; C main switch ; I*n* main reversing switch ; C*c* centrifugal regulator ; C*r* relay for regenerative control ; C*d* switches for changing from repulsion to series connections. M*n* main controllers ; S*mt* small motor for voltage regulation ; S*m*C small motor for actuating the main switch ; S*mi* small motor for main reversing switch ; S*ma* small motor for the starting controllers ; *dm* the starter for the compressor motors ; C*mi* the reverser for the compressor

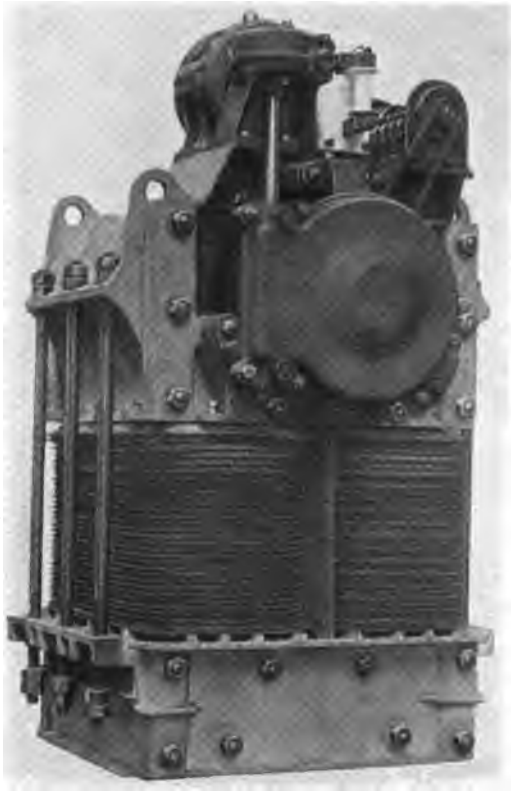


FIG. 95.—Transformer and Induction Regulator.

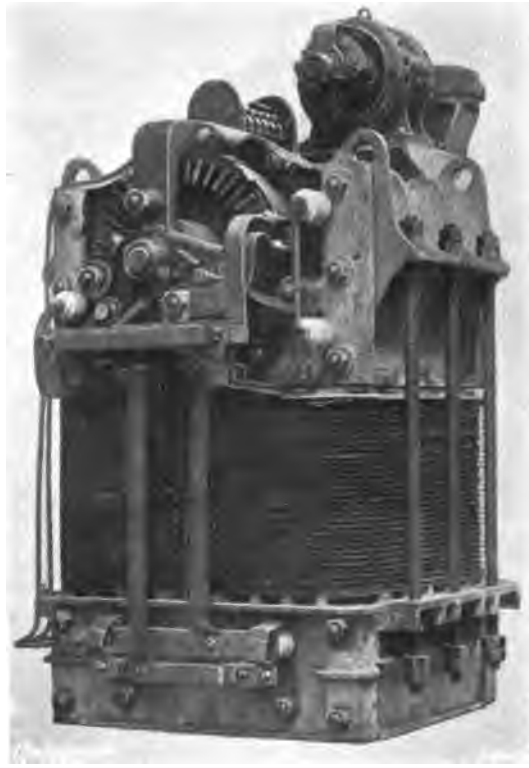


FIG. 96.—Transformer and Induction Regulator.

motors ; *trc* compensating transformers ; *tre* exciting transformers ; *rc* compounding resistance, and *mc* treadle switch.

From the foregoing it will be seen that the engine has two transformers. Mounted on the upper yoke of each there is an induction regulator, as shown in Figs. 95 and 96, the regulators serving to change the pressure at the terminals of the three motors. This arrangement is said to offer various advantages. The induction regulators are naturally of the single-phase type, and are connected in series with the transformers. The voltage they produce is either added to or subtracted from the pressure at the terminals of the transformers. By this means a pressure ranging between 200 and 760 volts can be obtained, the change taking place in a perfectly steady manner. It is claimed that with the induction regulators arranged in this manner the weight of the transformers is only slightly increased, the losses are small, and the scheme is far preferable to that of employing a large number of

contactors. The system obviates the necessity of using tappings on the secondary side of the transformers.

The stators of the induction regulators are magnetised by the windings of the transformers. There is a short-circuit connection between two points on the rotating element of each induction regulator, the object of this being to annul the inductive drop. The moving element of each induction regulator is moved by means of a small motor mounted at the top of the regulators, as shown in Figs. 95 and 96, the power being transmitted through two reduction gears having ratios of 1 : 31 and 1 : 33.

The main driving motors are of the compensated series type. But they are used as repulsion machines when starting the locomotive. For the purpose of changing from the repulsion to the series connection or *vice versâ* switches are fitted above each

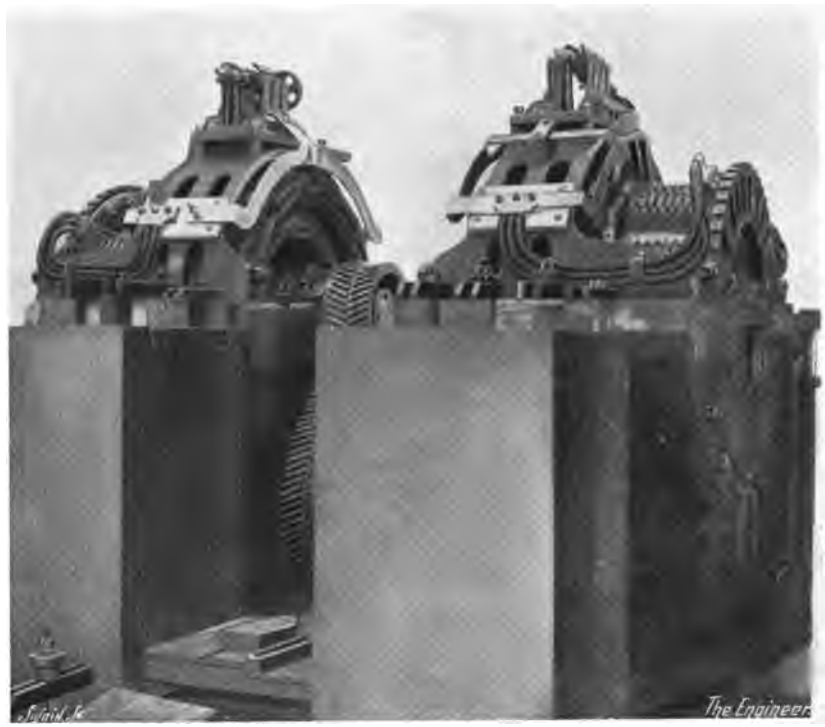


FIG. 97.--Motors Mounted on Test Plate.

motor, as shown in Fig. 97. The stator carries three windings, a main series winding, a compensating winding, and another winding which can also assist commutation. We can consider both these latter as compensating windings. They are placed in the same slots, and for series working they are connected in parallel as shown in Fig. 98. They have different numbers of turns and different cross-sections. These windings are displaced 90 electrical degrees from the main winding, and the compensating current is proportional to the working current. When running as series machines the maximum pressure applied to the terminals of each motor is 230 volts and the minimum pressure 67 volts. The starting or repulsion connections are shown in Fig. 99. Fig. 100 shows one of the 500 h.p. single-phase motors.

One object of working the motors as repulsion machines at the low speeds is that the commutation is more satisfactory under these conditions and an excellent starting torque can also be secured. When the motors are working as repulsion machines

the commutation windings are not connected in parallel, as shown in Fig. 98, but one winding is disconnected from the other, as shown in Fig. 99. The windings (two) of each

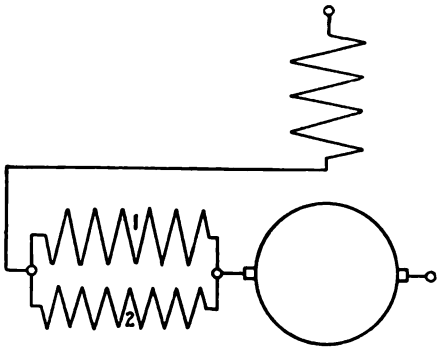


FIG. 98.—Running Connections.

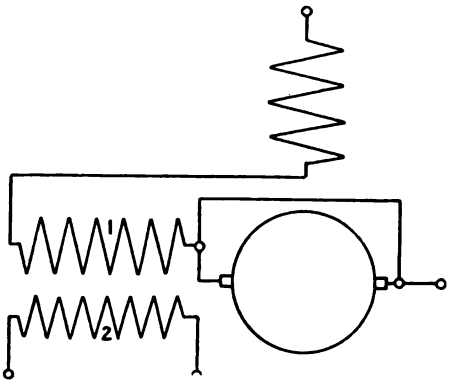


FIG. 99.—Starting Connections.

motor (see Fig. 99) are then connected in parallel. The result of this is that all the motors are compelled to run at equal speeds. If one of the motors has a tendency to run at a higher speed than the others, a higher pressure is produced in the winding

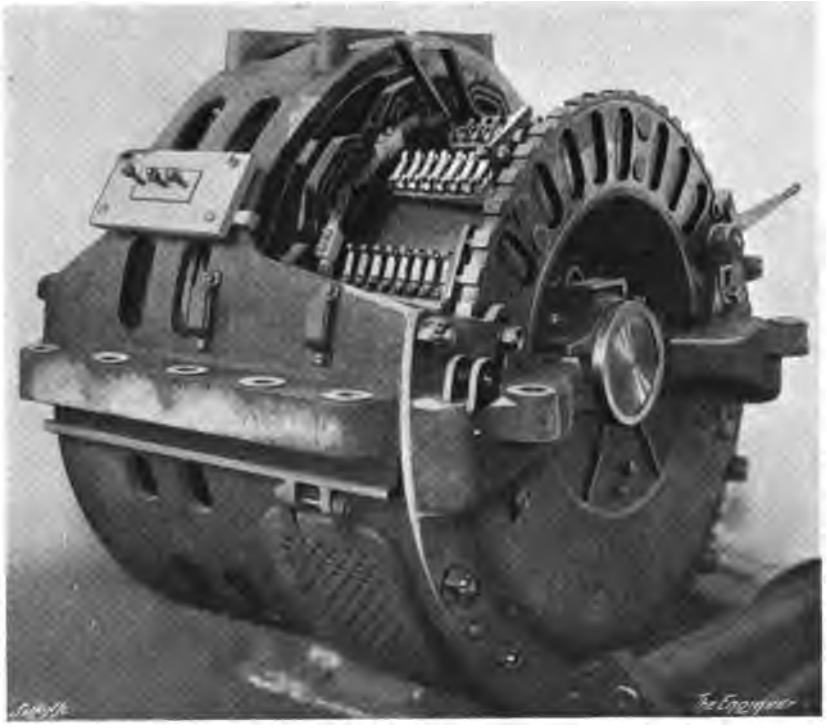


FIG. 100. —500 h.p. Single-Phase Motor.

(No. 2), which is connected in parallel with the corresponding windings of the other motors. Consequently a circulating current is set up in these windings which tends to increase the speed of the other driving motors and to reduce the speed of the machine

which is running too fast. It will therefore be seen that this arrangement obviates the necessity of using side rods. When the motors are working at the higher speeds they no longer operate as repulsion machines. They are all connected in series.

Another very interesting feature of this locomotive is the scheme adopted for returning current to the line when the engine is running down gradients. For this purpose the motors are separately excited. Current for exciting the motors is obtained from an auxiliary winding placed on the stator of the compressor motors, and displaced 90 degrees with respect to the main windings. The motors driving these compressors are of the Latour type. The main windings are fed at the supply voltage E_1, and the auxiliary windings supply to the field windings of the main motors a current which produces a field suitable for producing a voltage E_2 almost in phase with E_1. By properly adjusting the induction regulator the total secondary voltage E_3 can be made equal to E_2, and the main switch C to be seen in the diagram of connections, Fig. 94, can be closed. But as soon as the motors regenerate an appreciable phase displacement between the current and pressure takes place. To overcome the difficulty the transformer *tr* is provided, the primary of which carries the main current, whilst the secondary is connected to the terminals of the compressor motors. Moreover, to neutralise the phase displacement produced by the compressor motors themselves a compensating transformer *trc* is provided. The transformer *tre* and ohmic resistance *pc* produce a compounding effect on the compressor motors, so that they operate as well under ordinary conditions as they do when used in connection with the regenerative control system. It appears that with these special arrangements of auxiliary transformers, etc., the compressor motors work at approximately unity power factor when running as motors pure and simple as well as when also operating as phase transformers.

For regenerating it is necessary to couple the armatures of the main motors with the induction regulators and to connect the field systems with the rotary phase transformers, that is, with the auxiliary windings of the motor compressors. All the controlling operations are carried out by means of the small two-cylinder controllers and a foot pedal switch. From the diagram, Fig. 94, it will be seen that all the controlling operations are effected by small auxiliary motors. Signal lamps in each cabin indicate the position of the various controlling devices The cylinders B of the main controllers have five steps These drums control the direction of running and the braking operations. Cylinders A also have five stops, 00, 0, I, II, and III. When the handle is in the position 00 the control circuit is broken. The stop 0 corresponds to the minimum pressure from the transformers and induction regulators. At this point the low-pressure circuit is opened at the switch C. At stop I the low pressure circuit is completed, by the closing of the switch C. The transformers are then giving the minimum pressure. On placing the handle at position III the pressure increases automatically. The two cylinders A and B are interlocked so that they can only be operated in the right order. When the pedals are depressed the motors are connected as repulsion machines and when raised as series motors.

Small controlling motors have been used in preference to other arrangements, because they are reliable, simple, and cost little to maintain. These small motors are of the repulsion type, the stator having three windings, which are star connected. One of the terminals is earthed. By feeding the motors by means of one or the other of the remaining two terminals different directions of rotation are obtained. These small motors work at a pressure of 100 volts, obtained from a tapping taken from the transformers. Current for the control circuits can be taken from either of the transformers by simply actuating a switch. A current relay is used in the control circuit. It consists

of a small motor which can only rotate through a quarter of a revolution. During the movement of the armature an auxiliary contact can be closed or opened. This contact is interposed in the control circuit of the auxiliary motors, which actuate the induction regulators. If the main motor current exceeds a certain value the auxiliary contact breaks the feed circuit of the motors of the induction regulators and the pressure at the terminals of the main motors ceases to increase. When the current decreases the auxiliary contacts are again brought together, and the auxiliary motors of the induction regulators are then set into operation and the voltage increases as before. It is possible to cut this relay out of circuit by means of a switch placed near the controllers. It short circuits the auxiliary contacts of the relay. The main reversing switch *In* is to be seen at the top of the diagram. It is operated by the motor *Smi* controlled by the reversing controller.

To start the locomotive one of the foot pedals is depressed and the handle of one of the controllers A is turned. When the position III is reached the pressure at the motor increases automatically by reason of the movable elements of the induction regulators turning. The starting current is limited by the current relay in the manner described. But if it is desired to accelerate rapidly the current relay can be put out of action. Under these conditions it is necessary to watch the needle of the ammeter and to manipulate the controller in accordance with the reading. When the speed has been increased sufficiently for series working, the controller handle A is placed in the position II. In order to slacken the speed it is placed in position I. The pedal is released to change to the series connection for the higher speeds. The series connection can also be established automatically by the centrifugal regulator *Cc*.

But let us now return to the question of regeneration. Suppose that the motors are excited from the compressor motors in the manner described. The pressure at the terminals of the motors will rise with an increase of speed ; the excitation is nearly constant. The transformers are also developing a certain voltage, and as these are in series with the motors there is a certain resultant pressure at the low-tension switch, which, we will assume, is open. The regeneration relay *Cr* is energised at this voltage. When the pressure reaches a certain value the relay closes the low-tension switch through the medium of the motor *SmC*. Nevertheless, it is still necessary for the centrifugal regulator to close the circuit, and this only takes place at a speed above 20 km. per hour. When the circuit is completed between the motors and the transformers the rise of the pressure of the motors causes current to be sent back into the line. In order that this may occur it is evident that the pressure of the motors must always slightly exceed the opposing pressure of the transformers and induction regulators. Since the pressure of the former is constant, the speed at which regeneration occurs depends on the induction regulators. Therefore, to alter the speed at which regeneration takes place, it is simply necessary to change the voltage developed by the induction regulators. To increase the speed at which regeneration occurs it is necessary to raise the working voltage by means of the regulators, and to diminish the regenerating speed it is necessary to diminish the transformer voltage. The regenerating relay prevents the regulators from diminishing the pressure too much, and this limits the regenerated current. A voltmeter is also connected across the low-tension switch, so that when the pressure indicated is less than 120 volts the controller handle can be placed in the position II and the driver then waits for the action of the regeneration relay. The precise method of procedure is as follows :—First, the handle B is placed in the regenerating position. With the other handle in position III the voltage of the regulators is increased. When the voltmeter connected to the low-tension switch indicates 120 volts handle A is placed in position II, after which the relay

causes the low-tension switch to close. The relay in acting establishes the pressure on the motor of the low-pressure switch. This closes the circuit and regeneration commences. The current which is sent back into the line is recorded on the ampere meter. If it is desired to accelerate the engine whilst regeneration is taking place the handle A of the controller is turned to the position III. If, on the other hand, a reduction in speed is desired the handle is moved to the position I, just as when the engine is taking in current. When the speed falls below 20 km. per hour regeneration is automatically stopped by means of the centrifugal apparatus Regeneration can therefore only take place when the speed exceeds 20 km. per hour.

Some interesting tests have been carried out on this locomotive. The most troublesome gradient—17 mm.—is between Marquixanes and Prades, a distance of 5·3 km. Many curves are also met with on this part of the line. At the time of the official tests, however, the speed did not fall below the specified value with trains weighing 100 to 280 tons, although the pressure was not always maintained at 12,000 volts. The drop in the pressure was mainly caused by the small capacity of the plant. The following results were obtained on this 17 mm. gradient :—

Hauling load, tons	280	100
Speed, km. per hour	41	61
Power absorbed, kilowatts	1,100	850
Pressure on overhead wire	10,300	11,000
High-pressure amperes	120	83
Low-pressure amperes	1,625	1,100
Cos θ..	·89	·91
Low-pressure volts.	650	700

The above figures cover all the power used for auxiliaries, such as compressors, etc. At 12,000 volts the speed for a 280-ton train is 46 km. per hour, and for a 100-ton train 65 km. per hour. The power factor will be slightly improved at the higher voltage. Fig. 101 gives the speed attained, the kilowatts and amperes absorbed when starting the locomotive on this 17 mm. gradient. A speed of 34 km. per hour has been reached in two minutes, the low-pressure current not exceeding 2,100 amperes. The high-pressure current at starting was 72 amperes.

On starting the 280-ton train on this 17 mm. gradient slight sparking at the brushes of the motors was noticeable, but this was not at all serious. During the run no signs of sparking were observed. Commutation was also highly satisfactory when the motors were sending current back into the line. The energy supplied to the system when a 280-ton train is running down the 17 mm. gradient at a speed of a 38 km. per hour was found to be 400 kw. This corresponds to 40 amperes at 12,000 volts and ·83 power factor. With a train of 100 tons the power factor of the regenerated current is nearly unity.

Another interesting single-phase locomotive is shown in Fig. 102. This was submitted by Brown, Boveri & Co. for the Midi Railway. It is a standard gauge locomotive with the 2–6–2 wheel arrangement, and is equipped with two 750 h.p. motors of the single-phase commutator type. The locomotive is designed for normal speeds of 35—60 km. per hour, the maximum speed being 75 km. per hour. The pressure at the terminals of the motors is 1,000 volts. As in the case of the motor coaches used on the Martigny-Orsières railway, described elsewhere, the speed is entirely controlled by brush shifting, and the motors are of the Déri type. The rotor is quite independent of the stator so far as electrical connections are concerned, and each motor has two sets of brushes, one of which is fixed and the other movable. The speed and direction of rotation of the motors, and hence the speed and direction

of travel of the locomotive, are controlled by displacing the movable brushes in one or other direction.

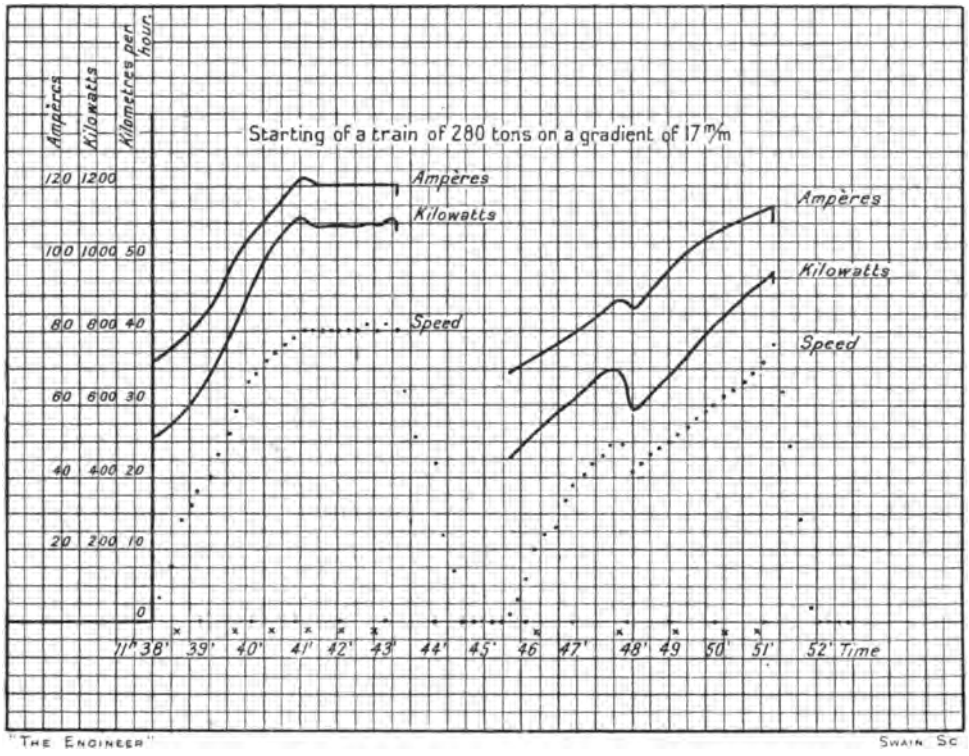


FIG. 101.—Starting Curves.

This is effected by means of a hand wheel in the driver's cab at each end of the locomotive. The direction of rotation of the motors is always opposite to that in

FIG. 102.—Brown-Boveri Locomotive.

which the brushes are displaced, and the speed increases with the angle of displacement. No starting or regulating resistance or reversing switch are therefore necessary. Like other firms which have adopted brush displacement for controlling the speed,

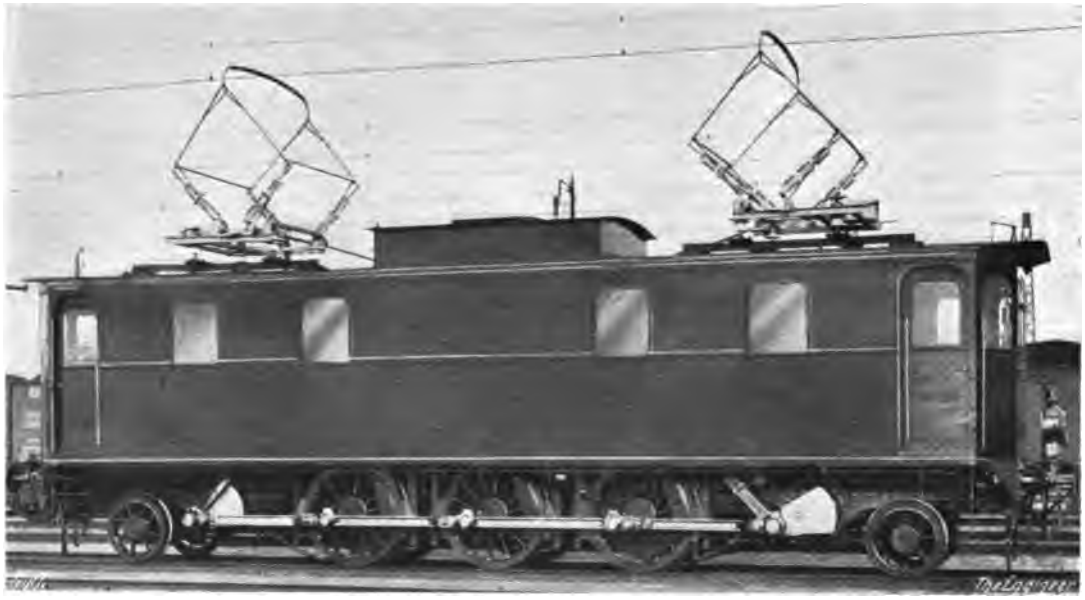


FIG. 103.—A.E.G. Goods Locomotive.

Brown, Boveri & Co. direct particular attention to the fact that this form of control has the advantage that the locomotive can accelerate quickly and smoothly, since the regulation does not take place in steps, as is the case with the usual type of controller, but is continuous from standstill to maximum speed.

FIG. 104.—A.E.G. Locomotive Hauling Train.

The illustration, Fig. 103, shows a large passenger and goods locomotive that has been built by the A.E.G. Company. A view of the same locomotive hauling a goods train is shown in Fig. 104. The total length of the locomotive measured over the

buffers is 13,140 mm., the diameter of the driving wheels 1,310 mm., and the diameter of the crank circle 540 mm. Altogether, the weight of the locomotive is 85 tons, and 54 tons of this is utilised for adhesion. Since there are three driving axles, the adhesion pressure per axle is 18 tons. The propelling power is derived from two motors, each of which is rated at 800 h.p. for one hour, and these two machines enable the locomotive to exert a tractive force of 12,500 kilos. on the draw bar. The maximum speed is 75 km. per hour. The motors drive the axles through two intermediate jack shafts which are placed between the end running axles and driving axles. The motors are so placed that the driving-rods are at an angle of 45 degrees with respect to the base of the locomotive.

The main motors are mounted high up in the body, and the transformer is placed in the space between the two machines. Contactor control has been adopted for varying the voltage at the motor terminals. The working current passes from the various transformer tappings of the main transformer through the magnetically operated contactors, through the stationary winding of the motor, and through a special exciter transformer. This latter supplies current for exciting the motor, the exciting current being fed into the rotor as in the case of the motors fitted to other locomotives built by the A.E.G. Company. This exciter transformer is constructed on the single-coil principle. In other words, it is an auto-transformer. Like the main transformer, this exciting or auxiliary transformer is provided with a number of tappings, and the pressure at which the exciting current is fed into the rotor is governed by contactors. But it is only at the higher speeds that this special voltage is impressed upon the rotor windings, since at normal speeds—*i.e.*, about 40 km. per hour—the armatures are short circuited. The motors then work as repulsion machines. This engine is also designed for regeneration on down gradients.

FIG. 105.—Interior of Driver's Cabin.

The interior of the driver's compartment of this locomotive is shown in Fig. 105, from which it will be gathered that the handle of the controller is provided with a knob, or " dead man's handle," which when released cuts off the power from the motors, and the locomotive is brought to a standstill. The reversing drum for reversing the direction of the motors is embodied in the same controller case as the main controlling drum. When it is required to cause the motors to regenerate, the reversing handle is turned to a marked point on the controller. There are also two other positions which give the motors the correct direction of rotation for forward and backward running of the locomotive. In the case of this locomotive, some of the contactors are mounted in a frame over the main transformer, whilst the remainder are fixed in cases at the ends of the motor compartment. The exciting transformer and motor-driven air compressor are also placed at the ends of the motor compartment. The two current collectors used on this locomotive are similar to those

employed on the locomotives constructed for the Dessau-Bitterfeld line, described elsewhere.

These collectors are raised and lowered by turning the compressed air cock in the driver's cabin. To facilitate the removal of the motors and transformer from the locomotive, a portion of the roof can be opened so that the heavy parts of the electrical equipment may be lifted out by means of a crane. It is worthy of mention that this locomotive has drawn goods trains weighing 1,500 tons at a speed of 40 km. per hour on fairly steep gradients. In order to determine the regenerating properties of the equipment, trials were carried out on the Dessau-Bitterfeld line, but owing to the absence of steep gradients on this railway, it became necessary to couple this large locomotive to another locomotive, the latter taking in current and the former returning it to the overhead wire. The results went to show that at medium speeds regenerative braking was quite practicable, and that an appreciable reduction in the output of the generating station can be brought about by adopting this practice.

CHAPTER IV

THE BLANKENESE-HAMBURG-OHLSDORF RAILWAY

ELECTRIC working was commenced on this line January 29th, 1908, and the traffic has been increasing ever since. It has already been necessary to extend the power station and coach shed on two occasions and to make other alterations. The Blankenese-Hamburg-Ohlsdorf Railway, constructed and worked by the Prussian

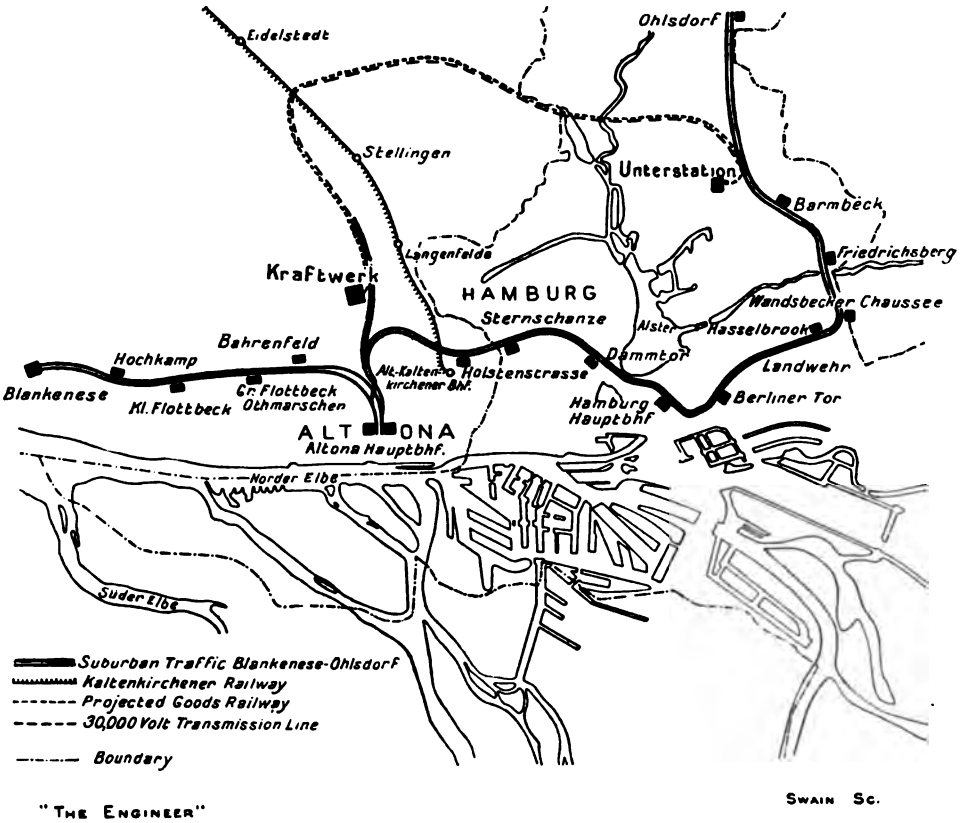


FIG. 106.—Map of the Blankenese-Hamburg-Ohlsdorf Railway.

State authorities, was the first railway with dense traffic to adopt the single-phase system in Germany. As the map, Fig. 106, shows, the line may be divided into one principal town section and two suburban sections. The western suburban section is 8·9 km. long, and extends from Blankenese to the main station at Altona. The town section proper is 10·7 km. long, and forms a connection between Altona and Hasselbrock, whilst the northern suburban section begins at Hasselbrock and ends at Ohlsdorf. There are seventeen stations, with an average distance apart of 1·67 km., the greatest distance between stations being 4·1 km., and the least ·6 km. The total length of the line is 26·71 km., and it is constructed with double lines throughout. At all the

intermediate stations the time allowed for stops is 30 seconds, whilst at the head station at Altona a one-minute stop is permitted. Under these conditions the total time required for covering the whole journey in either direction is 52 minutes, and the average travelling speed 30·7 km. per hour. There is a five-minute service on the town railway and a ten to twenty-minute service on the suburban sections.

The power station is situated about 1·5 km. to the north of the main railway station at Altona. Originally the engine-room contained four single-phase turbo-generators for supplying current to the railway, one lighting generator, two converters, and an engine-driven set for charging the battery. The first extension was made in 1909, when a large railway generator and a direct-current turbo-generator were added. In 1910 two other railway generators were put into use, making a total of seven turbo-generators of the Siemens-Schuckert type. The alternators generate single-phase current at a pressure of 6,300 volts and at a periodicity of 25 cycles per second. They run at a speed of 1,500 revolutions per minute, and have a capacity of 1,250 kw. at a power factor of ·75. It is possible to work the machines at 1,700 kw. for short periods. The generators are two-pole machines, and are controlled by

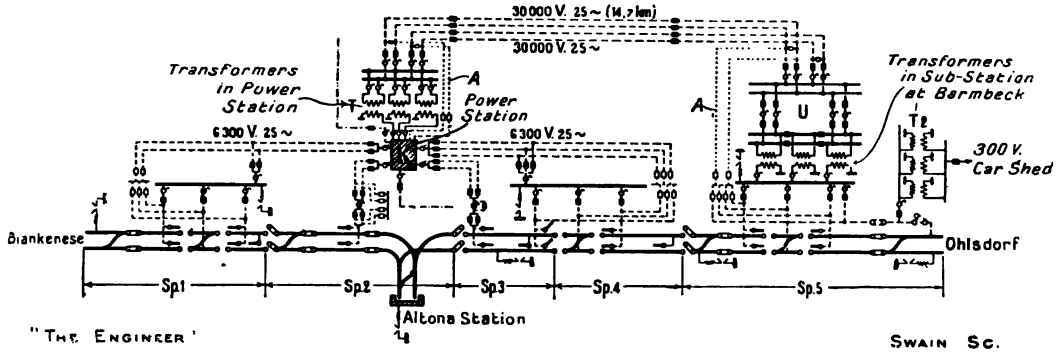


Fig. 107.—Diagram of Feeder Connections.

an automatic regulator which maintains the pressure within ± 5 per cent. of the normal value. Choking coils are used for limiting the short circuit current.

The lighting generator has a capacity of 600 kw., and supplies current at 6,300 volts and 50 cycles per second. It provides current for lighting the stations on the Altona-Ohlsdorf section and also for the goods yards. The direct-current turbo-generator works in conjunction with a battery, and furnishes current at 220 volts for driving motors, etc., in the power station. The two converters serve as spares for the lighting generator and the direct-current turbo-dynamo. There are three separate switchboard equipments corresponding to the above described sets. One deals with the single-phase current for working the line, another the alternating current used for lighting purposes, and the third with the direct current used in the power house.

The railway generators are controlled by oil switches, which serve for connecting all the main alternators on to a common bus-bar. Oil switches are also used for connecting and disconnecting the feeders. From the diagram, Fig. 107, showing the general scheme, it will be gathered that those sections of the railway near the power house are fed directly from the station bus-bars. It will also be noted that there is a 30,000-volt transmission line which runs to a sub-station at Barmbeck. An external view of this sub-station is given in Fig. 108. In order to raise the pressure to 30,000 volts three 867 kilovolt-ampere single-phase transformers have been put

down in the power house. The primary windings are connected to the bus-bars, and are therefore fed with current at a pressure of 6,300 volts. These transformers supply current at 30,000 volts to the high-tension transmission line. At Barmbeck the pressure is again lowered to 6,300 volts and supplied to sections of the overhead conductor at the Ohlsdorf end of the railway. The distributing and overhead equipment was supplied by Siemens-Schuckert, this firm being the contractor for the whole of the electrical work connected with the railway.

It will be seen from the diagram, Fig. 107, that the wiring of the railway is divided into five main sections, separated from one another. They are marked Sp1 to Sp5. The first section extends from Blankenese to Gross Flottbeck. Section insulators are interposed at each end of the section, and a three-fold distribution of the entire section is attained in the manner indicated in the diagram. Each of the three parts of this section is supplied with current by a wire having a section of 120 sq. mm. Oil switches are connected in circuit with these

FIG 108.—Sub-Station at Barmbeck.

wires as indicated in the diagram, and these serve to switch out either of the three conductors in the event of any disturbance on the line rendering such a procedure necessary. These switches—which are enclosed in boxes near the point of supply—are fitted with remote control gear so that they can be operated from the power house. The second section of the line extends from Gross Flottbeck as far as the section insulator behind the Altona station, and the third section from this point to the section insulator in front of the Hamburg Central Station.

An oil switch is interposed in each of the supply conductors, as explained when dealing with the first section. The fourth section extends from Hamburg Central Station to Hasselbrock, and the fifth section begins at Hasselbrock and ends at Ohlsdorf. From the diagram it will be perceived that the last-mentioned section is fed through the transformers in the sub-station at Barmbeck. Further, it will be noted that the arrangement of the switch gear and the general system of distribution corresponds to that of the first section. In the event of failure of a feeder the faulty conductor is switched out of circuit, and the section insulators of the particular section affected are bridged

over by horn switches, thus maintaining the supply. In addition to the section insulators for the five sections referred to, similar insulators are interposed in the contact wires at both ends of each station. Under normal conditions, however, these insulators are bridged across by horn switches, and it is only when it is desired to make the station wiring dead that these switches are opened. Horn lighting arresters protect the wiring from atmospheric discharges, and these are fixed at eight points along the line. Four of the feeders consist of bare copper wires, which are carried on bell insulators mounted on the masts which carry the contact line wiring. The current is returned to the power house by way of the rails and by conductors connected thereto.

For the purpose of avoiding accidents in the event of a breakage in the transmission wires, guard nets and other safety devices of a similar nature are used. The high-tension lighting wires for supplying current for lighting the stations between Altona and Ohlsdorf are also carried on the masts which support the contact wire.

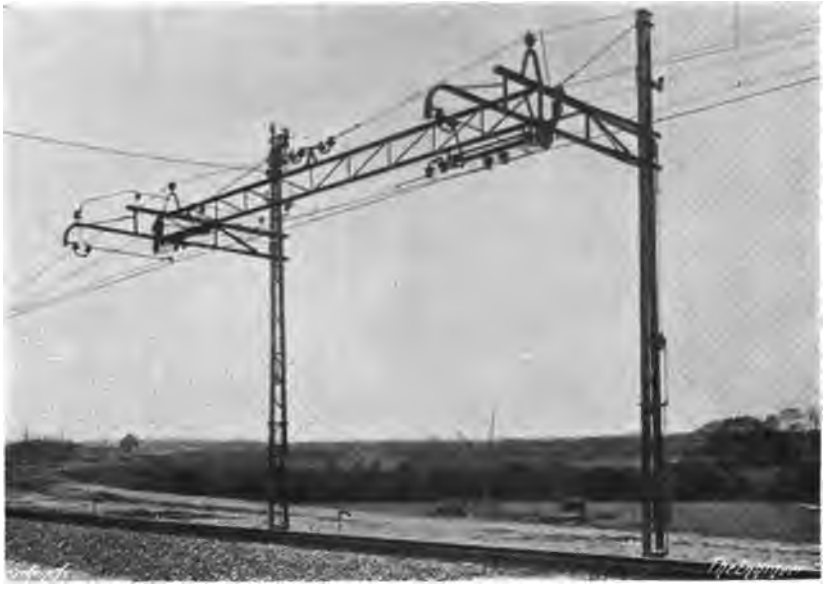


FIG. 109.—Automatic Tightening Gear.

In the case, however, of the 30,000-volt transmission line, which runs from the power house to the Barmbeck sub-station, the wires are for the most part carried on special lattice-work masts. A considerable length of the transmission line passes over agricultural lands. There are two circuits, which are entirely separated from one another. One of these can also be used for lighting on the railway, and by operating switches in the power house it becomes possible to supply the lighting load through the station at Barmbeck. This sub-station is a four-storey building, and is erected near the railway embankment. In the basement there are two electrically driven pumps. These supply the water for cooling the transformers, which is pumped from a well.

The switches for controlling the 6,300-volt current are on the ground floor of the building, together with the apparatus for protecting the line against atmospheric disturbances. On the first floor there are the switches and transformers for the 30,000-volt supply, together with the transformers which reduce the pressure just

mentioned to 6,300 volts for working the railway. The lightning protective apparatus for the 30,000-volt wires is placed on the second floor, together with the distributing

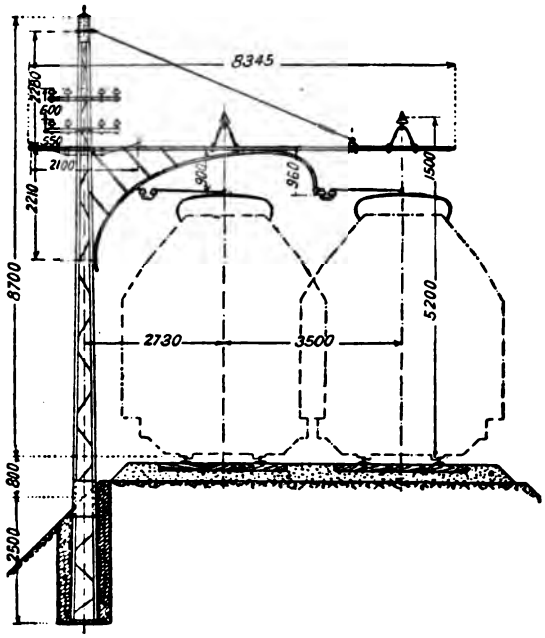


FIG. 110.—Bracket Arm Construction.

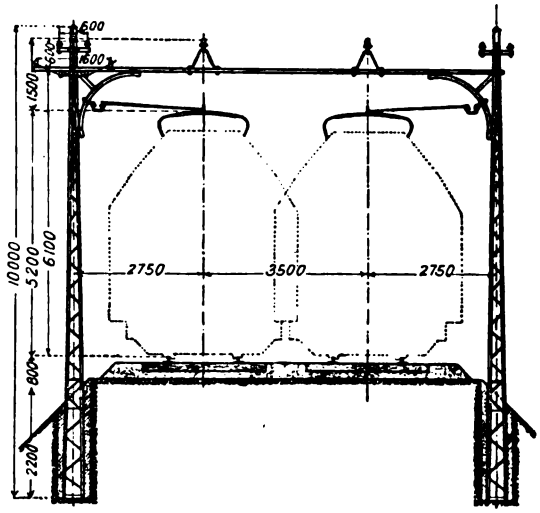


FIG. 111.—Overhead Construction.

bars for the 6,300-volt current. The switch gear and the measuring apparatus used in connection with it are of the same design as those in the power house. In the event

FIG. 112.—Overhead Construction near Bahrenfeld Station.

of anything happening to the transformers at the Barmbeck sub-station it is possible to cut the transformers out of circuit and to feed the fifth section of the railway with

6,300-volt current over the 30,000-volt transmission lines. For this purpose branch wires A, A are provided between the primary and secondary windings, as shown in the diagram, Fig. 107. It will, of course, be understood that these wires can only be brought into use when the transformer switches are open.

As regards the overhead equipment, the multiple suspension system, as adopted by Siemens-Schuckert, is employed. The contact wire is of hard-drawn copper, and has a section of 90 sq. mm., whilst the auxiliary wire is of steel, and has a diameter of 6 mm. The suspension wire is made up of seven strands, and has a section of 35 sq. mm. To avoid side movement of the wire the latter is held by struts, which are of course insulated from the supporting structures. Although these struts prevent the wire from moving sideways, they allow it to move freely in the direction of the axis of the track.

FIG. 113.—Method of Suspending Wires under Bridge at a Station.

The wire is tightened by means of weights, which ensure uniform tension at all temperatures. One of the automatic tighteners is shown in Fig. 109. The masts of the section insulators and those supporting the tightening gear are 9 m. apart. Automatic tightening of the catenary cables and auxiliary wires is not necessary, since, under considerable differences of temperature, the tension of these is practically unaltered, and, moreover, the slight variation of the tension of these wires has no influence on the contact between the bow on the motor coaches and the overhead conductor. This form of overhead equipment is described more fully elsewhere; see for example the Rotterdam and Schevening line.

On the section from Sternschanze to Hamburg, which passes through the most beautiful part of Hamburg, ornamental masts are used, with a bracket arm which spans two tracks. Each mast is connected to the rails by a tinned copper wire of 50 sq. mm. section. The general design of a bracket arm as used for two lines on one part of the railway is shown in Fig. 110, whilst Fig. 111 shows the design where cross supports are used on the section from Barmbeck to Ohlsdorf. The arrangements shown in Figs. 110 and 111 are employed where there is insufficient room between the lines for the erection of a central standard. The arrangement shown in Fig. 111 presents the advantage that the lighting and power wires can be entirely separated from one another.

On one part of the route, namely, at the Bahrenfeld station, where there are several goods lines running side by side, the contact wire is supported by span wires attached to standards on either side of the permanent way, as shown in Fig. 112. This construction was adopted in order to avoid the expense of the ordinary cross supports.

At some station bridges, such as shown in Fig. 113, the contact wire is only about 5 m. above the rails, and in order to remove the insulators from the direct action of the smoke from the steam locomotives the special system of suspension illustrated was adopted. Here it will be observed the wires are supported by struts constructed of piping at the ends of which insulators are fixed in the manner shown. For bonding the rails two copper wires having a section of 35 sq. mm. are used. No high-tension wires are taken into the carriage shed. These are equipped with special low-tension wiring, which is 1 m. nearer the rails than the high-tension wires. This wiring is worked at a pressure of 300 volts, and is supplied with current from special transformers, as indicated on the diagram, Fig. 107. Special current collectors are fitted to the motor coaches for collecting the current at this pressure. For the purpose of testing sections of the high-tension wiring after repairs, etc., special testing coaches

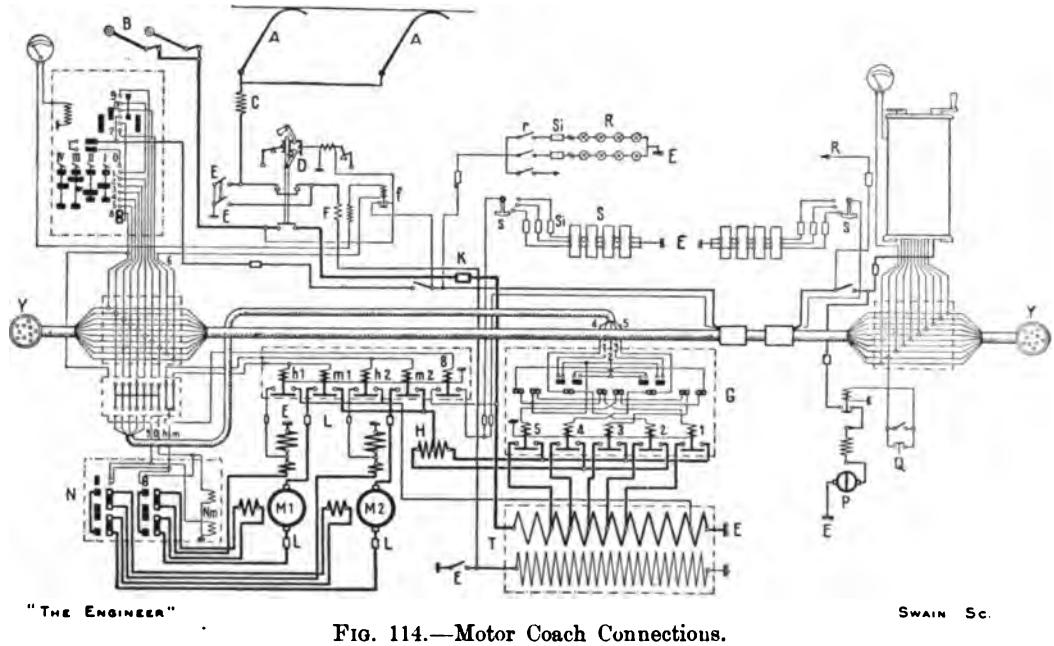


FIG. 114.—Motor Coach Connections.

are provided, which are worked with accumulators. The batteries on these coaches have a capacity of 183 ampere hours, and supply current to two driving motors.

Passenger trains on the Blankenese-Hamburg-Ohlsdorf Railway are made up of motor and trailer coaches, two such coaches constituting a train unit. Trains made up in this way have a maximum of four units, so that altogether there are eight coaches. A one-unit train has 124 seats, a two-unit 252, a three-unit 380, and a four-unit 508. On the railway proper the current is collected from the overhead wire by a bow current collector which is raised and lowered by compressed air. Special precautions had to be taken to insulate the collecting gear from the roofs of the motor coaches, owing to the exceptionally damp atmosphere which prevails in Hamburg. A diagram of connections for one of the motor coaches is given in Fig. 114. Here A is the high-tension current collector, B the low-tension collector, C the choking coil for lightning protection, D the 6300 and 300-volt switches, E the earthing switch, F a current transformer, f a high-tension current release.

It will be gathered that there are two groups of contactors. Those in one set are marked 1 to 5 and those in the other group h_1, m_1, h_2, m_2. The contactors m_1 and m_2 are termed the main contactors, and, as will be seen from the diagram, are in the main

motor circuit. Contactors h_1 and h_2, on the other hand, are auxiliary contactors, and are connected to the auxiliary windings of the motors. The contactors marked 1 to 5 connect up different tappings on the secondary side of the transformer, whilst the other contactors join up the armature and field windings of the motors. Further, it will be observed that there is a reactance coil at H which serves to prevent the motor circuit being broken when the contactors alter the transformer connections. Careful inspection of the wiring of the contactors 1 to 5 will make this point clear.

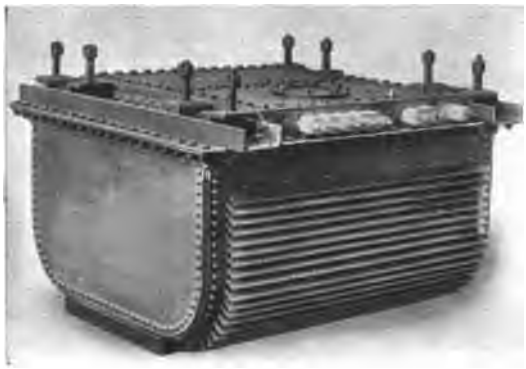


FIG. 115.—Transformer.

It has been explained that there are two current collectors, one for the low-tension current in the coach shed, and the other for the high-tension current derived from the outside trolley wire. These two voltages, however, do not involve the use of two transformers or the provision of additional windings on the coil of the ordinary transformer, since when the motor coaches are working at 300 volts the current passes into the secondary of the transformer T, and under these conditions it is obvious that the secondary winding acts as the winding of an auto-transformer.

It is unnecessary to consider every detail on the diagram of connections for the motor coaches, since the functions of most of the switches and other apparatus are obvious. It may be mentioned, however, that the main driving motors are shown at M_1 and M_2, and the reversing switch at N. P is the air pump motor, R the lamps for lighting the coach, S the switch for the heating apparatus, Y the coupling for connecting

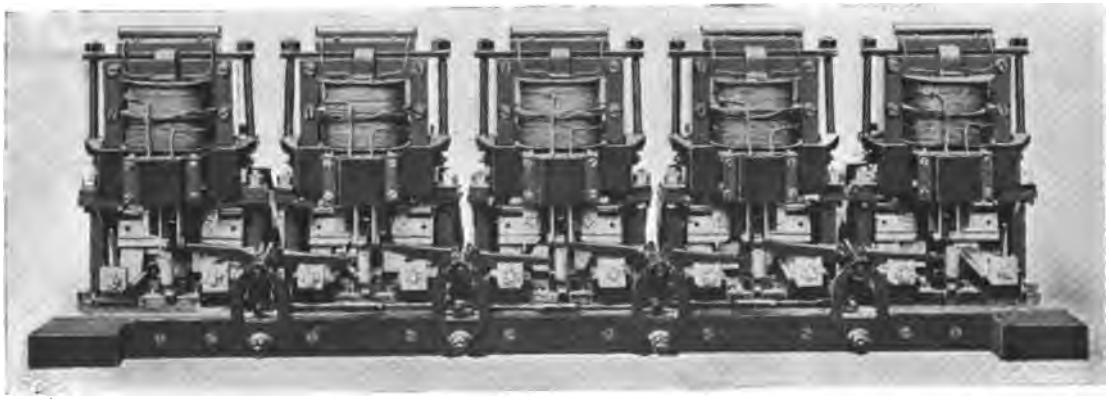


FIG. 116.—Group of Contactors.

up the controller leads with other motor coaches on the train, Q the compressed air governor, and S_1 fuses. A main transformer as used on the motor coaches is shown in Fig. 115, and a group of contactors in Fig. 116.

The coach shed is at the end of the Hasselbrock-Ohlsdorf section of the railway, and near the Ohlsdorf Station. The workshops are also situated at this point. Seventy-eight coaches can be sheltered in the shed, and the coaches enter at one end of the shed and leave at the opposite end. An electrically-operated jacking arrangement has been erected in the shed for lifting the coaches.

THE DESSAU-BITTERFELD RAILWAY

IN the early part of 1911 an electric locomotive ran for the first time on a German main line, namely, on the track from Dessau to Bitterfeld. This experiment proved so satisfactory that the Prussian State Railway authorities decided to extend the system at one end, through Leipzig to Halle, and at the other end as far as Magdeburg, and also to electrify a new experimental section from Lauban to Konigszelt. Passenger and goods carriages must be capable of passing from one railway to another, and for this and other reasons electric locomotives are being employed.

Electric locomotives possess important advantages. It is possible to use large motors which can be placed in a high position and carried on springs, thus obviating troubles arising from a low centre of gravity. Another important feature is that owing to the small number of motors and their accessible position the equipment can easily be inspected. The Prussian State Railway authorities specified that all electric locomotives should be provided with one or two open-type motors, placed high up in the locomotive body, and that the power should be transmitted to the wheels through cranks on to a jack shaft, and thence through the side rods to the driving wheels. The design of the motors and other electrical equipment was left entirely to the various manufacturing firms concerned.

The Dessau-Bitterfeld line constitutes the central section of the 118 km. of track between Magdeburg and Leipsig, to which places, as stated above, the electric service is to be extended. With a view to obtain the requisite cooling water for condensing purposes, the power station for the electrified lines has been erected on the river Mulde, and in the neighbourhood of Bitterfeld. Current is generated at a pressure of 3,000 volts and at a periodicity of 15 cycles per second. This pressure, however, is raised to 60,000 volts with the aid of oil-cooled transformers, and the current is transmitted at this voltage to a sub-station. This high-tension transmission is carried out by means of cables, and up to the present they have worked perfectly satisfactorily At the time of writing good progress is being made with the conversion of the railway between Magdeburg, Leipsig and Halle, and it is expected the line will be ready for traffic under the new conditions before the summer of 1914. The trials on the converted section are to be extended with the view to gaining further experience, and also training the staff. The working pressure, it is reported, is being increased from 10,000 to 15,000 volts, and the distance between the gantries supporting the overhead work extended from 245 ft. to 328 ft., an arrangement which will not only enable the signals to be seen more clearly, but will reduce the cost of porcelain insulators. Work on the new plant at the Muldenstein power station is well advanced. The new generating plant will comprise seven turbo-alternator sets, of which four, each of 4,000 kw. capacity, will supply current for the line. The electrical energy will be transmitted as single-phase alternating current at a voltage of 60,000 to three transformer stations located at Wahren, Marke and Gommern, the latter being the maximum distance (44 miles) away. The length of the section is about 94 miles, representing a total of, approximately, 310 miles of track. Automatic oil switches with maximum current releases are used for switching in the cables and transmission

lines at the power station, and they are operated from the switchboard with electric remote control. The current enters the sub-station for the Dessau-Bitterfeld lines at a pressure of 60,000 volts, and is transformed down by means of air-cooled transformers. Here, again, remote control switch gear is employed, the main switches being of the oil-brake type and fitted with maximum current releases. In the power station the automatic switches are fitted with time-limit attachments.

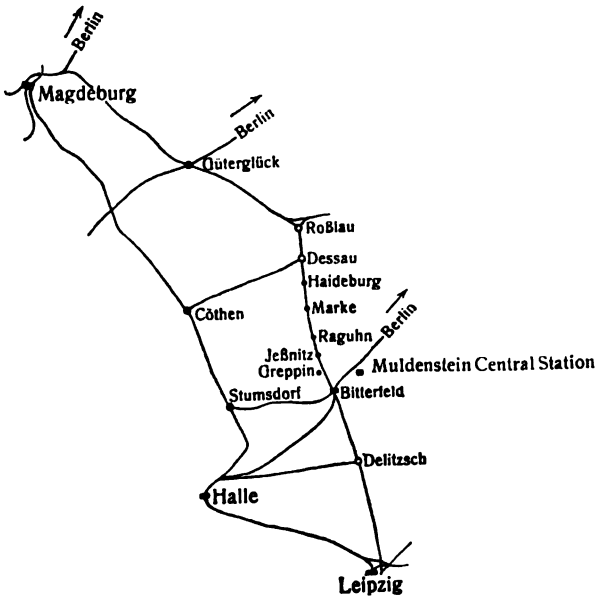


FIG. 117.—Map of the Dessau-Bitterfeld Railway.

The Dessau-Bitterfeld line (see map, Fig. 117) is 27 km. long and has a double track. In all there are six intermediate stations, namely, Greppin Dorf, Greppin Werke, Jessnitz, Raguhn, Marke, and Heideburg. The most extensive track arrangements are to be found at Greppin Werke, Jessnitz, and Raguhn stations. The whole of the track from Dessau to Bitterfeld is at present fed directly from the single sub-station, but for the purpose of the extensions feeders will run along the structures supporting the overhead wire to the other sub-stations under construction. The erection of the overhead line at the Bitterfeld station and at Greppin Dorf, Greppin Werke,

FIG. 118.—Overhead Equipment on Open Track.

Jessnitz, and Raguhn stations, together with the track between these stations, was entrusted to the Allgemeine Elektricitäts Gesellschaft. The overhead line is constructed with single catenary suspension, the wire which carries the current being suspended at distances of 6 m. by vertical dropper wires from a steel wire rope stretched in the form of a catenary. Iron gantries support the line, and they are placed about 75 m. apart. In the majority of instances ordinary U girders are fixed to the standards erected on either side of the track.

A view of the overhead construction as adopted for straightforward open track is given in Fig. 118. When the spans are great, however, the cross girders are stiffened by tie-rods as shown in Fig. 119. Another system adopted for long spans is shown in Fig. 120. In the case of this latter illustration the gantries span seven tracks, and are 70 m. long. An advantage of this arrangement is that it is possible to use a small number of standards, and in addition it presents a good appearance. The

FIG. 119.—Overhead Construction at Jessnitz Station.

overhead line is divided at distances of about 1,000 m., and in the centre of these the line is fixed, whilst at the two ends it is stretched by automatic tightening devices, so that the separate wires are under approximately the same tension at all temperatures.

The overhead wires are assembled together at the sides of the tracks and put into place afterwards. There is therefore no necessity to block the line whilst the overhead equipment is being erected. At stations, however, it is of course practically impossible to complete the work at the side of each track; but as there are generally several tracks, one can easily be blocked, and when the work has been completed it can be opened again and another blocked. In Fig. 121, A is the strain wire, B the parabolical suspension wire, C the conductor, H vertical droppers, KK^1 clutches, W a loop formed by the wires A and B passing below the cross girder, and F a flexible

wire to which insulators S and S′ are attached. This latter wire connects the clutches K and K′ and transfers the strain from one side of the support to the other,

FIG. 120.—Overhead Construction at Bitterfeld Station.

because the loop W hangs loosely. The flexible wire F is insulated by the insulators S and S′, and it rests on the insulator D on the cross support. Galvanised clamps, as

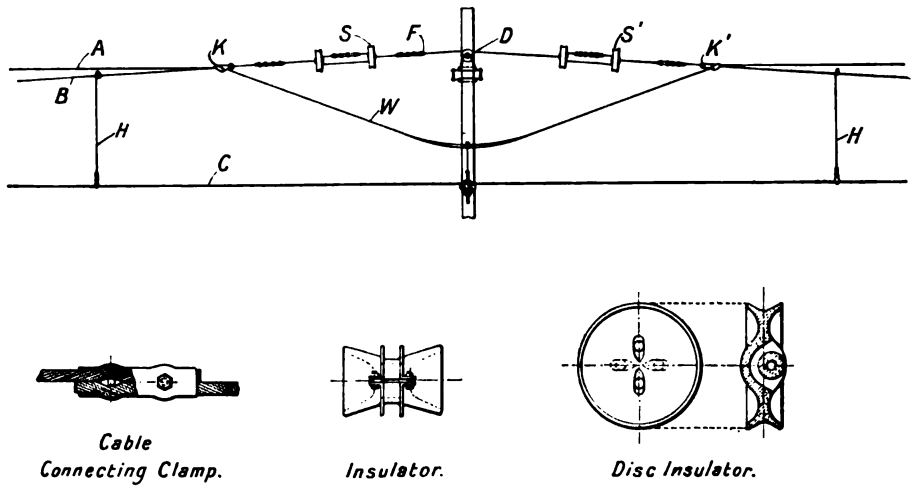


FIG. 121.—Details of Overhead Construction.

shown in the lower part of Fig. 121, are used to join the wires where necessary. It will be perceived that the strain wire A is provided to insure a regular stretch on the parabolical carrying wire over the whole length of a section from one pair of weights

to the other pair at the ends of the same section. The strain wire has very little sag. As the illustration, Fig. 121, shows, the clutches K and K′ join the strain wire and the parabolical suspension wire together at each suspension point on the cross support, transferring their strain to the flexible wire F. The loops formed under the girder by the two first mentioned wires are necessary in case it is desired to regulate the wires after they have been erected. When the temperature increases, the carrying wire B expands, thus increasing the sag and decreasing the strain. The strain wire A expands about the same amount, since it is made of the same material. Therefore its strain also decreases, and as it has very little sag its strain decreases considerably more than that of the other wire B. The weights at either end exert a constant strain, and thus stretch both wires until the stress is balanced and the drops remain exactly the same as before, since for a given constant strain there is always a constant sag. The above also applies to the contact wire, as this is also connected to the weights at the ends of the sections. Other details of the overhead construction are given in Fig. 122. Stays of steel tubing are employed for fixing the contact wire laterally. On this steel tubing a contact wire clamp is mounted, which serves for holding the contact wire fast. A joint is provided at the opposite end of the steel tubing, and this allows the latter to turn in a vertical direction.

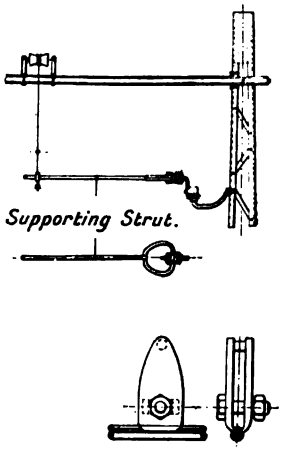


FIG. 122.—Details of Overhead Construction.

The stay joint is mounted on a cap cemented to the bell insulator, and has play, so that within certain limits the stay can also turn horizontally, corresponding to the longitudinal movement of the contact wire. For the purpose of ensuring uniform wear of the locomotive bows the overhead line is erected in zig-zag fashion, the suspension points each deviating about 50 cm. from the centre line of the track. The hard-drawn copper wire, which has a circular section, is provided with two side grooves, in which the line clamps can grip, as shown in Fig. 122. In the case of the main line the sectional area of the overhead conductor is 110 sq. mm., whereas the conductor used for the sidings only has a sectional area of 70 sq. mm. Galvanised steel rope with a section of 42 sq. mm., and consisting of seven separate wires, is used for the wire A. The wire B consists of seven separate galvanised wires, and has a section of about 20 sq. mm. For the vertical droppers steel wire 3 mm. in diameter is used. To allow the contact wire to rise slightly as the collector bow passes over it and without bending the suspension wires, the latter are provided with a loop at the lower end, which allows the contact wire to have a free vertical movement of about 5 cm. Pressed brass clamps grip the contact wire in the manner shown in Fig. 122.

The construction of the automatic tightening devices will be understood by reference to Fig. 123. It will be seen that the sections which come together are extended past one another for a distance of one span, and are connected to weights, which provide the necessary tension as explained. Fig. 123 shows that the weights run in guides, which are mounted on the lower part of the masts. These anchoring masts are constructed of heavy angle iron. In the middle of the span the two ends of the adjoining sections, which overlap, are connected to each other in such a manner that satisfactory current collection can be secured when the bow glides from one section to the other. This will be clear on referring to Fig. 123.

Naturally the track is divided into sections, which can be switched out when

required, so that on the occurrence of a breakdown it is not necessary to switch the current off the whole line. At a section division the arrangement of the contact line is the same in principle as a tightening section, but in this case the two adjoining sections are not connected in the middle of the span, but are suspended separately on a special light support, which is termed a section isolating gantry. On the masts of this support horn switches are mounted, to which the contact wires which overlap are connected. Under ordinary conditions these switches are closed, and are only opened in the case of emergency, so that the sections behind them are cut out of circuit. These switches are to be seen at the sides of the masts in Fig. 124. They have double insulation, and are operated by a winch placed at the side of the mast. Under ordinary working conditions the two main tracks are completely separated

FIG. 123.—Wire-tightening Posts.

from one another electrically. But switches are provided which can connect any two sections of the main tracks together. Normally these switches are open.

The contact lines over the station sidings are connected to the main lines at the stations, and special arrangements are provided for isolating the contact wire over the loading tracks. These lines can only be energised after a warning signal has been given, and these signals are automatically operated by the line switch in such a manner that the line can only be subjected to the pressure after a certain interval has elapsed. The switch is actuated by a crank mechanism and two contact devices, one of which is connected to a signal bell, whilst the other feeds a lamp circuit. Matters are so arranged that the switch does not work until a period of about thirty seconds has elapsed from the time the crank was first operated. During these thirty seconds the bell rings, and at the same time the lamps placed on the masts adjoining the loading tracks light up. The lamps remain alight so long as the contact wire is under pressure.

At the Bitterfeld station the contact lines of the different tracks are arranged in four groups, which may be interconnected in such a manner that on the occurrence of a breakdown in one group the others are not affected. All curves on the open track have a large radius, so that with the distance adopted between masts, *i.e.*, 75 km., no special arrangements are necessary to make the contact wire follow the track. But at the stations a number of " pull-offs " had to be provided. At these points the contact line is anchored by means of a special light mast erected on the inner side of the curve. Fig. 120 shows a curve of this kind with three tracks at the Bitterfeld station. At the north end of this station there is a bridge, and at this point there is only a distance of 4·83 m. between the lower side of the bridge and the upper edge of the rails. Considerable difficulty was experienced at this point, and the overhead line could not be laid over the centre of the track. The difficulty

FIG. 124.—Section Division on Main Line.

was overcome by using two contact wires over each track in the manner shown in Fig. 125. Owing to the shape of the bow this enables the necessary clearance to be obtained. This arrangement necessitates the use of a current collector 2,400 mm. wide. It is at this point where the Bitterfeld station can be cut off from the open track, and, owing to this, the two inner wires from the open track are anchored to a mast erected between the two incoming tracks on one side of the bridge, whilst the two outer contact wires from the station are supported by special anchoring masts on the other side of the bridge.

The full line pressure is used inside the locomotive shed, and this, of course, necessitates special precautions. Four overhead lines are used in the shed, and a switch for each of them is fitted on the shed roof. These lines can only be energised after warning signals have been given. An illuminated sign is suspended over each of the tracks, and these light up separately when the switches belonging to different

FIG. 125.—Arrangement of Overhead Lines at Bridge.

tracks are closed, and a signal bell also rings at the same instant. When one of these switches is opened, it automatically earths the contact line to which it belongs. It is also possible to disconnect and earth the lines over the turntable shown in Fig. 126, outside the shed.

FIG. 126.—Arrangement of Wires at a Turntable.

From this it will be gathered that an angle iron ring is suspended over the centre of the turntable, and that the various overhead wires terminate in this ring. This arrangement permits any desired number of shed tracks to be provided with contact lines, according to requirements. The current returns by way of the rails, which are connected together by means of copper bonds and cross-connections. The contact lines for the two tracks are connected up separately to the sub-station with the aid of bare copper conductors. They are switched in with the aid of oil switches placed in the sub-station. Galvanised stranded copper cables connect the rails with the other pole of the supply system. The lightning arresters provided for protection against excess pressures are adjusted to operate at a pressure of about 15,000 volts.

FIG. 127.—A.E.G. Electric Locomotive Hauling Train.

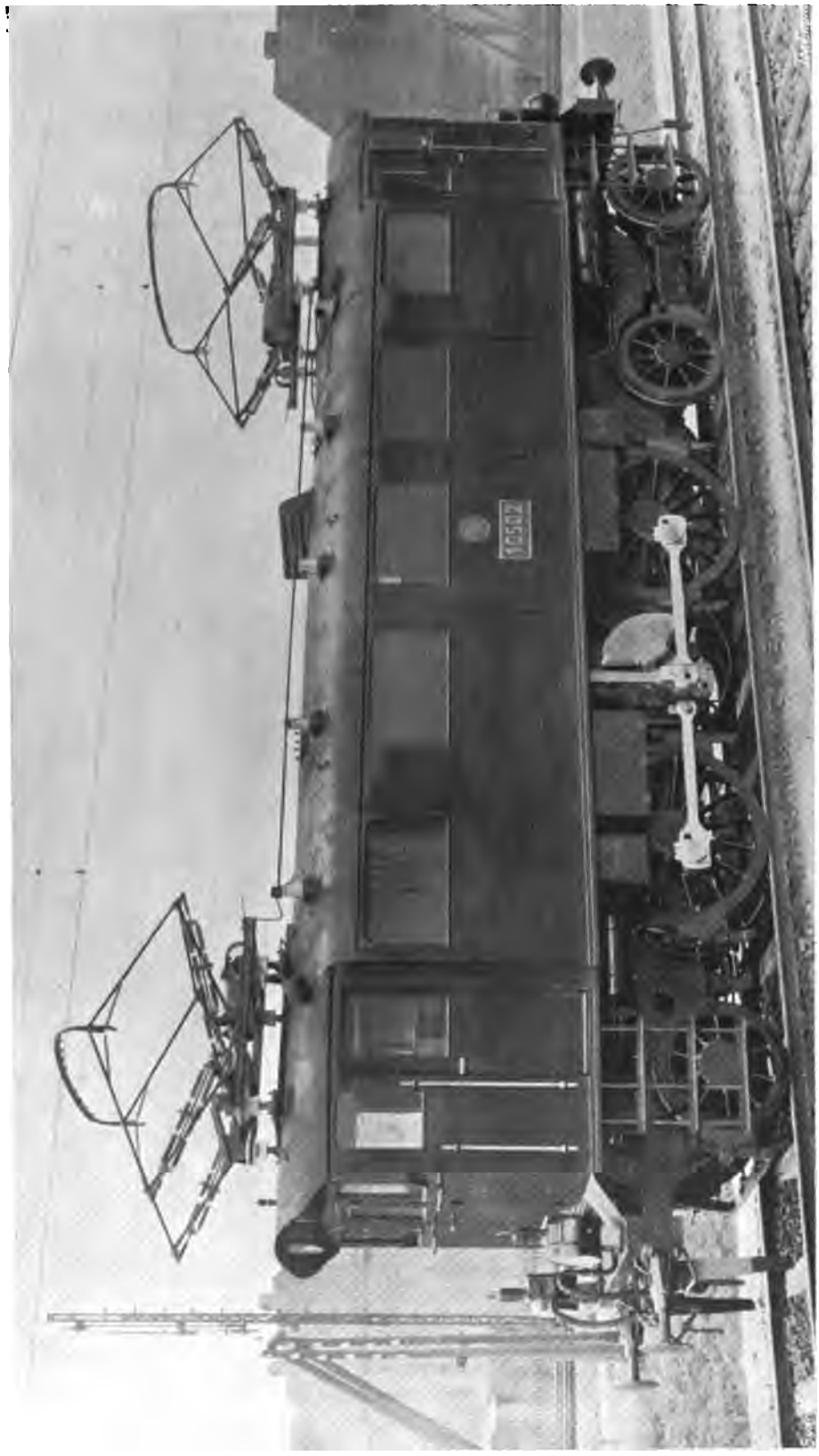


FIG. 128.—A.E.G. Passenger Locomotive.

There are two distinct types of locomotives—one for goods and the other for passenger service. It is possible, however, that when the electric system is extended to Magdeburg and Halle it may be found advisable to deal with the local traffic by means of motor coaches. The express passenger locomotives built by the A.E.G. Company have an axle arrangement corresponding to that of the well-known "Atlantic" type of steam locomotive. As will be seen from the illustrations, Figs. 127 and 128, the two leading axles are combined in a two-axle bogie truck. The total length of the 2 B I express passenger locomotive is 12·5 m. over buffers, the fixed wheel base 3 m., and the guided length ·6 m. When the locomotive is

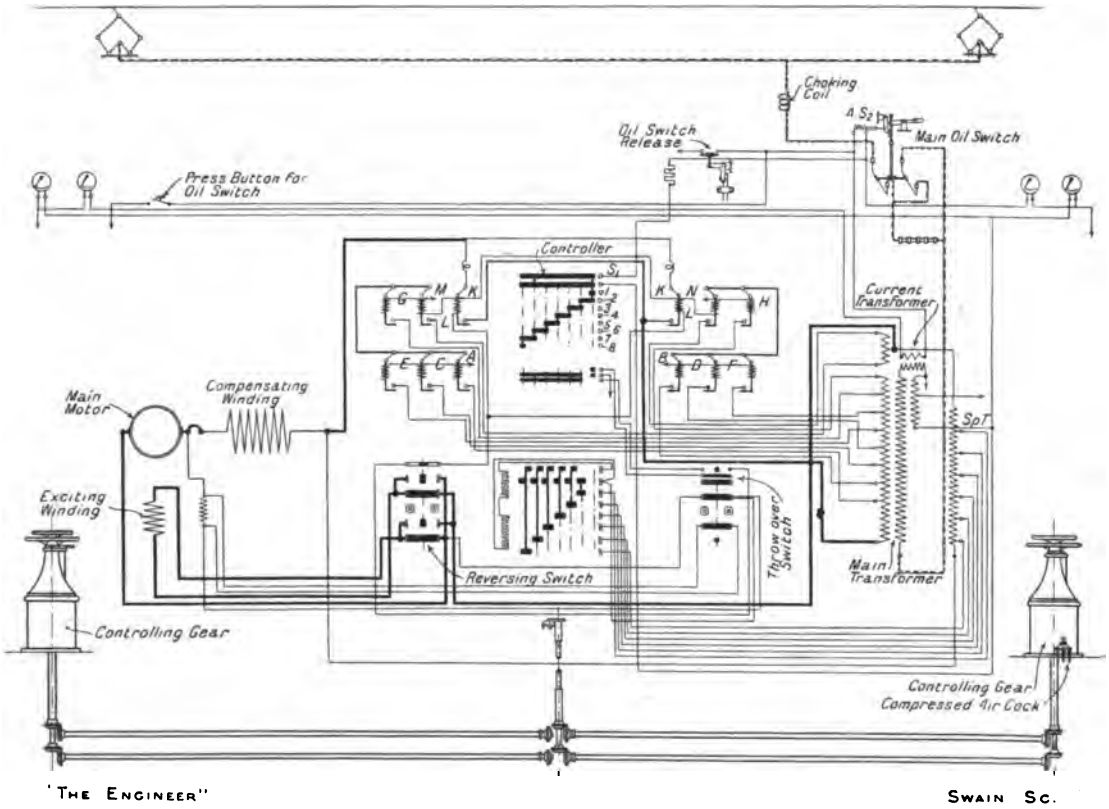


FIG. 129.—Locomotive Connections.

running at its maximum speed, viz., 110 km., or, say, 69 miles per hour, the driving wheels revolve at about 400 revolutions per minute.

Two driving axles are driven from a crank on the motor. The latter is mounted high up in the locomotive body, in accordance with specifications issued by the Prussian State Railway authorities. This parallel crank drive permits of an almost perfect balance being obtained, so that the locomotive runs smoothly at the highest speeds. The driving rods work vertically.

To obtain a permanent parallel position of the motor with respect to the intermediate crank or jack shaft, a cast steel connecting piece is mounted between the two shafts. It is rigidly bolted to the frame and surrounds the crank shaft on the one side and the motor shaft on the other. The intermediate crank shaft bearing is constructed in four parts, which may be adjusted both vertically and horizontally by means of wedges.

An interesting feature connected with these bearings is that a safety device is provided in the form of a fusible plug which is placed in the bearing and connected with the compressed air accumulator. An alarm whistle is also connected up with the bearing, so that in the event of the latter warming up and the fusible metal melting, compressed air is supplied to the whistle and the driver is warned before any damage arises. A single-phase commutator motor having an hourly rating of about 1,000 h.p. is used for propelling the locomotive.

The casing of the motor is fixed to two strong cross girders of the locomotive frame, and can be accurately adjusted by means of wedges and pressure screws. The motor is of the open type, and the design is such that easy access may be obtained to the commutator and brushes. The motor bearings as well as the intermediate crank shaft are oiled by a drip lubricator. From the diagram of connections, Fig. 129, it will be gathered that regulation of the tractive force and speed is effected by an ordinary contactor control system. Current is collected from the overhead wire by means of two current collectors. From these it passes to a choking coil, which protects the motor and other apparatus against excessive pressures, and after having passed through this coil it is conducted to the main oil switch. The latter is fitted with auxiliary and main contacts. From the oil switch the current passes to the high-tension winding of the main transformer and from the latter through a current transformer to earth.

The different transformer voltages are obtained by means of the contactors A, B, C, D, E, F, G, H, whilst the circuit is broken by the remaining four contactors connected in parallel, in two pairs. From any particular tapping on the secondary of the transformer the current passes from the corresponding contactor to the reversing switch, which reverses the current in the main exciting winding of the main motor, this reversal of current reversing the direction of rotation of the main motor. It next passes through the armature of the motor and the compensating winding, and then through the two contactors K and L to the other end of the secondary of the main transformer.

In addition to the main transformer a "voltage divider" S*p* T is provided, which also has a number of tappings, and by means of these the ratio between armature and stator voltages can be adjusted to suit different speeds. The main controller which regulates the tractive effort and speed is to be seen in the middle of the diagram. It will be perceived that this controller has two separate drums which can be revolved independently of one another. The upper drum regulates the tractive force and the lower drum adjusts the voltage from the "divider" S*p* T so as to secure satisfactory commutation.

Both these drums are actuated by the controlling hand wheels in the driver's compartments. Positions corresponding to various speeds are marked on the lower hand wheel, so that the driver can easily adjust the latter to the correct position in accordance with the speed indicator. At starting, the armature of the motor is short-circuited by means of a throw-over switch operated by the compressed air cock, but after a certain speed has been reached the armature is connected in series with the stator winding. Another interesting feature is the oil switch release, which is operated by the brake and prevents the switch being closed when the brake is on. There is also a press button for releasing the oil switch from the driver's cabin. The controlling current for the contactors is supplied from some independent turns of the main transformer.

The contactor chamber adjoins the machine compartment, and is so arranged that the main contacts are accessible from the side gangways of the locomotive,

whilst the auxiliary contacts may be reached from the motor compartment. The master controller stands in the centre of the contactor chamber, the reversing controller and the throw-over switch for connecting up the armature when starting up being placed under the contactor equipment.

It will be seen from the illustrations of the express passenger locomotives, Figs. 127 and 128, that two pantograph current collectors are employed for collecting the current from the overhead wire. These work in ball bearings, so that they can easily follow any alteration in the height of the contact line.

FIG. 130.—Interior of A.E.G. Express Locomotive.

At first current collectors of the bow type were used, but at high speeds they were found unsatisfactory. It was not possible to counteract the effect of the heavy wind pressure. The collectors now used, however, are said to have proved quite satisfactory. A side view of the motor is shown in Fig. 130. Fig. 131 shows the interior of the driver's compartment. The two controlling hand wheels are clearly visible. The speed indicator is to be seen just above the upper hand wheel, and above this the voltmeters and ammeters are placed. On the right of the controller, the brake valve is situated, and on the left the handle for the

compressed air sand distributor, and at the side of this the switch for operating the air pump. The handle for admitting compressed air to the whistle is placed in front of the window, and the two pressure gauges for the compressed air brake are mounted close to it. A lamp for lighting the driver's cabin is suspended from the roof.

Tests made at Bitterfeld indicated that these locomotives are capable of developing a maximum tractive effort at starting of 9,500 kilos. The average starting

FIG. 131.—Driver's Compartment on A.E.G. Express Locomotive.

acceleration with a train weighing 280 tons was ·19 m. per second per second, this being better than the guaranteed value, viz., ·15 m. per second per second. To arrive at the efficiency a number of trial trips were carried out. Seven journeys with short intervals between were made from Bitterfeld and Dessau and back with a train weighing 250 tons. On one journey, from which the hourly rating was determined, the weight of the train was 350 tons. With an external temperature of 20° C., the maximum temperature of the motor was 70° C. at the end of the seven journeys, notwithstanding the fact that a considerable number of starts had to be

made, which had not been allowed for. The illustration, Fig. 132, shows a group of A.E.G. electric locomotives as used on this railway. The locomotive to be seen on the left is for goods service.

The goods locomotives constructed by the A.E.G. Company are capable of running at a maximum speed of 70 km., or, say, forty-four miles per hour. As will be seen from the illustration, Fig. 133, the axle arrangement is entirely different to that of the passenger locomotives, the whole weight in this instance being used for adhesion. Measured over the buffers, the total length is 10·5 m., whilst the total length of the wheel base is 4·8 m. The driving wheels are 1·05 m. in diameter. The locomotive shown in Fig. 133 is capable of developing a maximum tractive effort of approximately 10,000 kilos., measured on the periphery of the driving wheel. Like the express passenger locomotive, the engine under consideration is fitted with a compressed air brake of the Knorr type, and also a hand brake. It will be gathered that the system of driving corresponds to that of the express passenger locomotives. But in this case the motor is not placed directly over the intermediate shaft. It is fixed so that the driving rods are at an angle of 45 degrees with respect to the base of the locomotive. This arrangement produces a much more favourable distribution of stresses on the intermediate or jack shaft.

The two cranks on the intermediate shaft are set at an angle of 90 degrees with respect to one another, and a rigid connection is obtained between the motor shaft and the intermediate crank

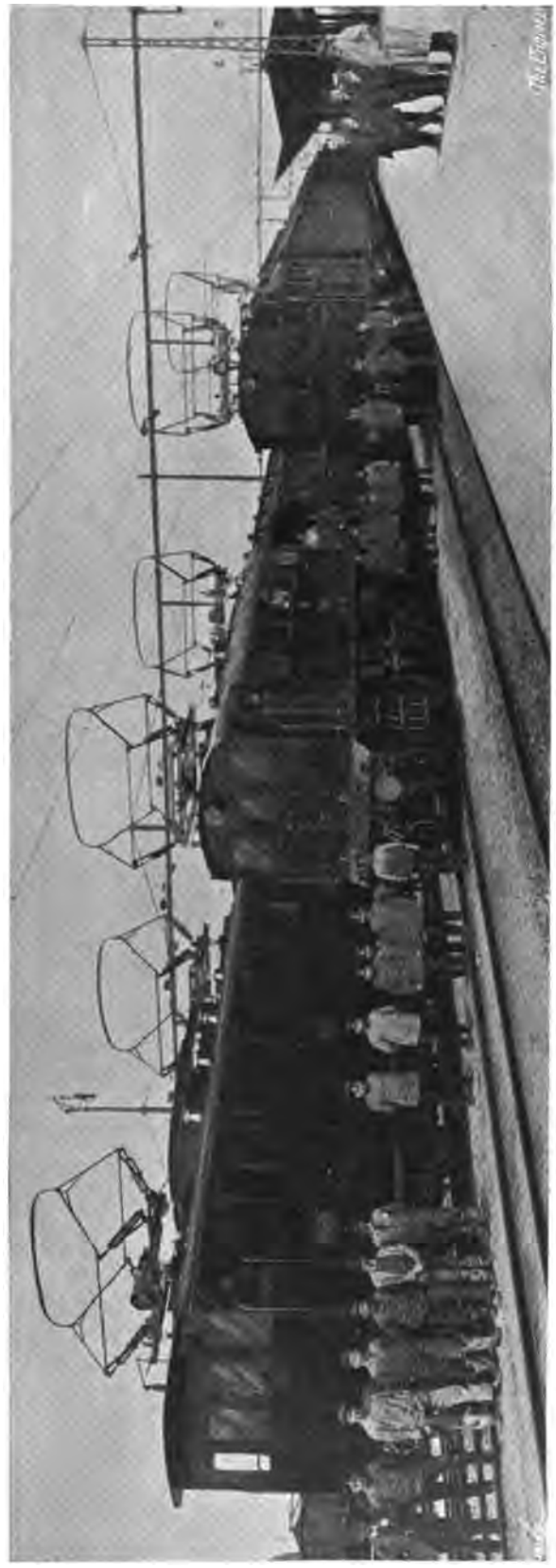


FIG. 132.—Group of Passenger and Goods Locomotives.

shaft by the use of a steel casting, which is bolted to the frame. The intermediate crank shaft, motor bearings, and the other parts of the driving mechanism, correspond to those on the express locomotives.

An alternating-current commutator motor, having an hourly rating of 800 h.p., is used for propelling the locomotive. A side view of the motor is given in Fig. 134. So far as the external appearance is concerned, the motor closely resembles those used in the express passenger locomotives. But in the case of this goods locomotive a different method of controlling the motor has been adopted. The speed is varied partly by shifting the brushes, and the direction of rotation is determined by the direction in which the brushes are displaced from the neutral axis. In addition to varying the speed by brush displacement, however, the motor's voltage is changed by the same method as that adopted in the locomotives previously described, namely,

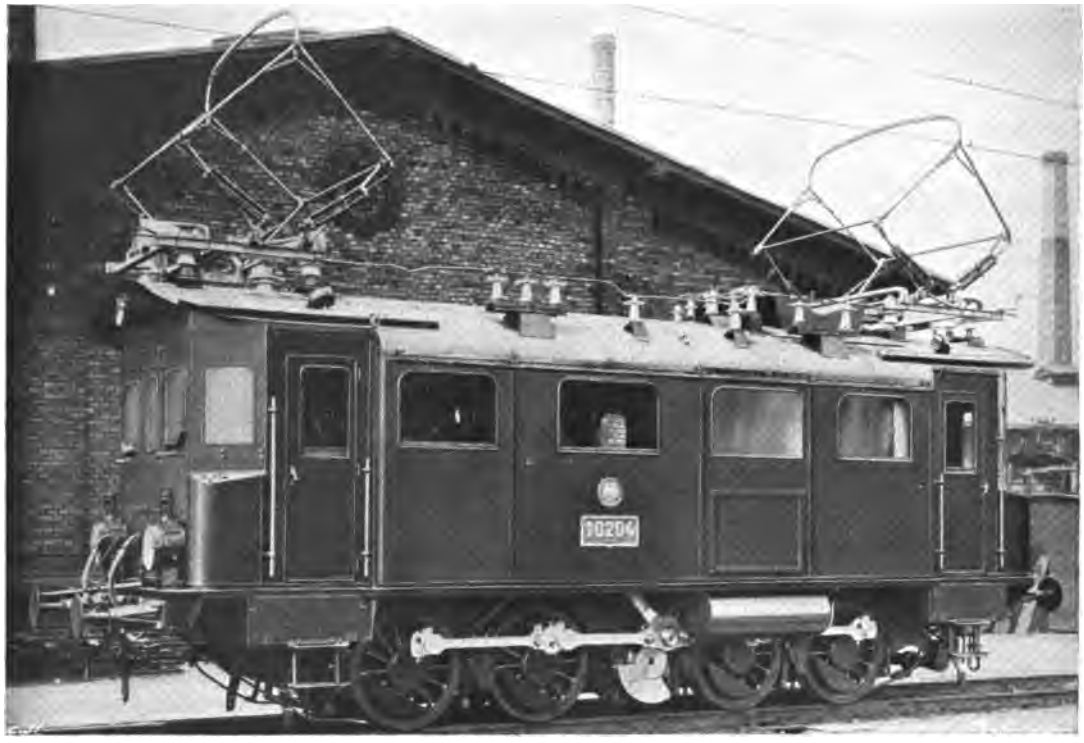


FIG. 133.—A.E.G. Goods Locomotive.

by altering the ratio of the primary and secondary voltages of the main transformer. Tappings are brought out from the secondary winding for this purpose. Moreover, in accordance with the practice adopted on the passenger locomotive, a second transformer is used, which is connected as a step transformer, and enables the ratio of the voltages in the armature winding and the compensating winding to be regulated. The arrangement of the high and low tension auxiliary circuits for lighting and the compressed air motor corresponds to that of the express passenger locomotive.

At each end of the engine is a driver's compartment, which contains the apparatus for controlling the motors. To enable shunting operations to be carried out with ease a controller with two hand wheels is placed at each side of the driver's cabin. Fig. 135 gives a view of one of the driver's compartments of a goods locomotive. Indicating devices are connected with the controlling gear, and mounted

above the controlling wheels in the manner shown in the illustration. The upper indicator gives the brush position, and the lower indicator the power the motor is developing. This locomotive has a transformer room, which adjoins one of the driver's compartments, and in this the main transformer is placed. A wide passage has been provided on each side of the transformer pit, so that access may be obtained to the machine compartment. The latter merely contains the main driving motor, the main controller, and the motor for driving the compressor. All the cables between the transformer controller and main motor have been made as short as possible. The method of supporting the motor is very similar to that adopted in the passenger locomotives. The lubrication of the bearings is also carried out on similar lines.

Since speed variation is partly effected by shifting the brushes, it is clear that the controlling gear differs somewhat from that already described. The brush shifting is effected by means of a screwed rod, which is controlled from the driver's cabins, and in order to enable the brush rocker to move with a minimum amount of friction the latter is mounted on rollers, so that it can turn freely. The rollers on which the brush rocker turns are visible in the illustration, Fig. 134. Although the locomotives now under consideration have been designed for goods service, they have also been employed for passenger trains. Owing to the high starting torque which the motors develop, the acceleration is very rapid, so that, in spite of the lower maximum speed, no difficulty has been experienced in running these locomotives in conjunction with those designed for passenger service and in maintaining the schedule speeds.

FIG. 134.—800 h.p. Motor for Goods Locomotive.

Besides these goods and passenger locomotives, the A.E.G. Company has also constructed another special type to the order of the Prussian State Railway authorities. This is intended for heavy train service and for use on steep gradients, similar, for example, to those which exist on the Lauban-Königszelt line in Silesia, which at the time of writing is being electrified. This locomotive is designed for hauling express trains at speeds up to 110 km., or, say, sixty-nine miles per hour, and heavy goods trains at lower speeds. In this 1.D.1. locomotive the first running axle is combined with the second axle, which is a driving axle, and the next driving axle with the second running axle, so as to form bogie trucks of the Krauss Helmholtz type. This arrangement is said to enable the locomotive to negotiate curves with great ease. The locomotive is equipped with two motors, each of which has an hourly rating of 900 h.p., and gives a maximum tractive force of 10,500 kilos. Power is transmitted to both working axles by means of a crank drive, both motors working on to an independent jack shaft supported between the two centre driving axles. As in the case of the locomotive just described, the driving-rods are inclined at an angle

of 45 degrees with respect to the base of the locomotive. This arrangement enables the stresses on the intermediate crank shafts to be favourably distributed. In this instance, an induction regulator is used for controlling the pressure at the motor terminals, as in the case of the Siemens locomotives, described below. The armature voltage is regulated in accordance with the method already described, and two hand wheels are provided in the driver's compartments for pressure regulating purposes.

The motors are placed near the centre of the locomotive, and the transformer is fixed between them. To enable the transformer to be properly ventilated it is

FIG. 135.—Driver's Compartment in Goods Locomotive.

raised a few inches above the base of the locomotive. The induction regulator is placed near one of the driver's cabins. Near the other driver's cabin the motor-driven air compressor is placed, and also a boiler which provides steam for heating the carriages. Owing to the fact that the carriages are also used on other lines where steam locomotives are employed, steam heating must be adopted. The boiler is heated by means of resistance coils through which current passes. A supply of water for use in the boiler is carried in tanks, and this is automatically fed into the boiler as occasion demands. Sufficient water is carried for a four hours journey. The following are the principal dimensions of the locomotive :—Length over buffers, 14·1 m.; length of wheel base, 9·7 m.; diameter of driving wheels, 1·5 m.; diameter of other wheels, 1 m. The weight on each driving wheel is 16 tons, and the total weight for adhesion, 64 tons. The maximum speed is 110 km., or, say, sixty-eight

miles per hour. Since there are two motors each capable of developing 900 h.p., the total power available for propulsion is 1,800 h.p. The mechanical portion of this locomotive was constructed by Kraus & Co., of Munich.

A Siemens-Schuckert locomotive is shown in Fig. 136, and the same engine hauling a train in Fig. 137. It is designed for passenger service and is capable of hauling a train weighing 370 tons continuously at a speed of 70 km. per hour, its maximum speed being 130 km. per hour. It will be gathered that the locomotive has two coupled driving axles, and that the two leading axles are combined in a two-axle bogie truck. The fixed wheel base is 3 m.—say, 9 ft. 11 in.—and the total

FIG. 136.—Siemens-Schuckert Passenger Locomotive.

length of the locomotive over the buffers is 12 5 m.—say, 41 ft. When ready for service the locomotive weighs 73·5 tons, and 45·5 tons of this is accounted for by the electrical equipment. The weight on each driving axle is 16·4 tons, and that on the bogie axles 13 tons. The weight on the rear axle is 14·7 tons. Thus the weight for adhesion is 32·8 tons.

In view of the high speeds at which the locomotive travels the mechanical portion has been made very strong. The 30 mm. frame plates are stiffened with numerous cross struts, and where the heavy electrical equipment is placed by cross pieces of cast steel. The springs of the driving axles are connected to one another by a system of levers, and the springs of the rear guiding or pony axle with those of the adjacent axle by horizontal equalising levers. Westinghouse quick-brake equipment has been

FIG. 137.—Siemens-Schuckert Locomotive Hauling Train.

adopted, and this acts on all the axles of the locomotive, the driving axles being braked on both sides and the other axles on one side.

For propelling the locomotive a Siemens-Schuckert single-phase series compensated motor is employed, similar to that shown in Fig. 138. This machine does not belong to the locomotive now under consideration, but to another which will be described later. It serves, however, to show the general appearance of the single-phase motors as used on these high-speed locomotives.

A claim made for this type of railway motor is that in comparison with other machines of the same class it is capable of giving a greater output for the same external

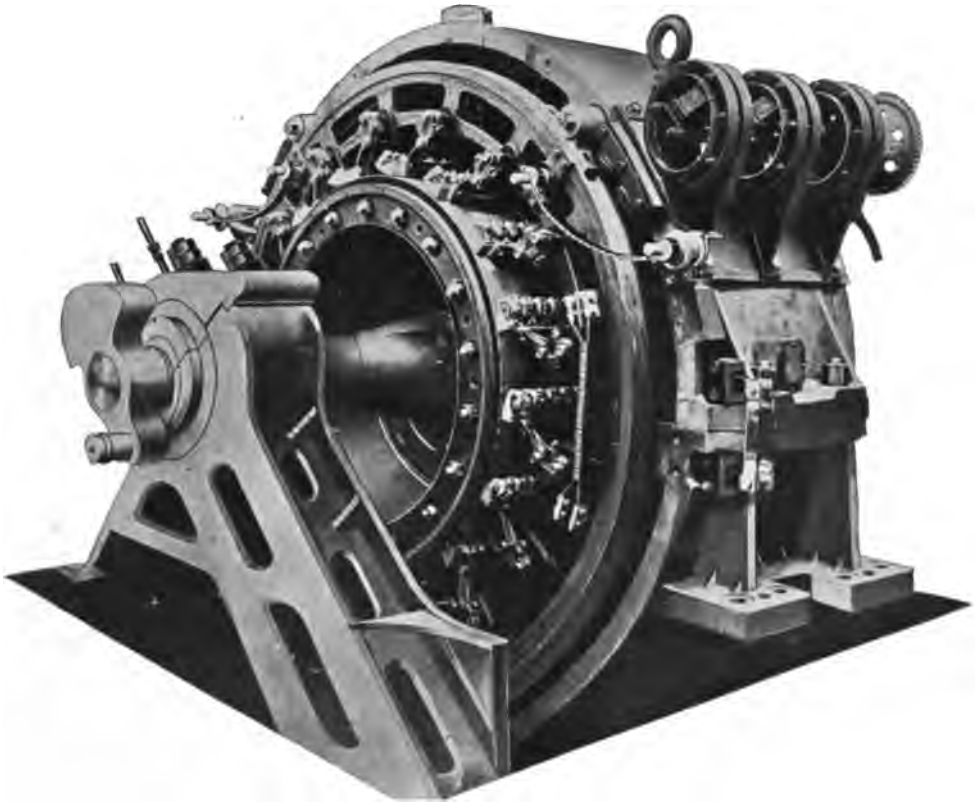


FIG. 138.—Siemens-Schuckert Single-Phase Motor.

diameter. The stator is built in two halves, and the upper half can be lifted off, and the armature can therefore easily be inspected. Owing to the fact that the ring carrying the brushes can be revolved in the stator casing, the lower brushes can be turned round to the upper part of the machine so that the brushes can be conveniently handled. A hand wheel and toothed gearing are provided for the purpose of shifting the brushes in a similar manner to that usual with large multipolar dynamos. Reversing switches are to be seen at the side.

From the diagram of connections, Fig. 139, it will be seen that the current for driving the motor is taken from the secondary winding of the main transformer in accordance with the usual practice. The primary of this transformer is connected to the current collectors and earth. For the purpose of controlling the motor the secondary winding of the transformer is divided into five sections, as shown in the diagram.

But to obtain a gradual and perfectly uniform variation in the voltage supplied to the motor, an induction regulator is employed which is connected in series with the various tappings by means of contactors. This is an ingenious arrangement, which provides a convenient means of gradually increasing and diminishing the motor's voltage.

It is of course possible to make an induction regulator assist or oppose the main pressure. For example, if one of these regulators be connected in series with a feeder, there is one position of the movable member of the regulator which gives no boost. By turning the movable member through a certain angle the voltage of the regulator rises and ultimately a maximum boost is obtained. Further movement of the rotating element will reduce the boosting pressure, and continued movement through a certain angle brings the boost to zero. Similarly, the boosting voltage can be made to attain

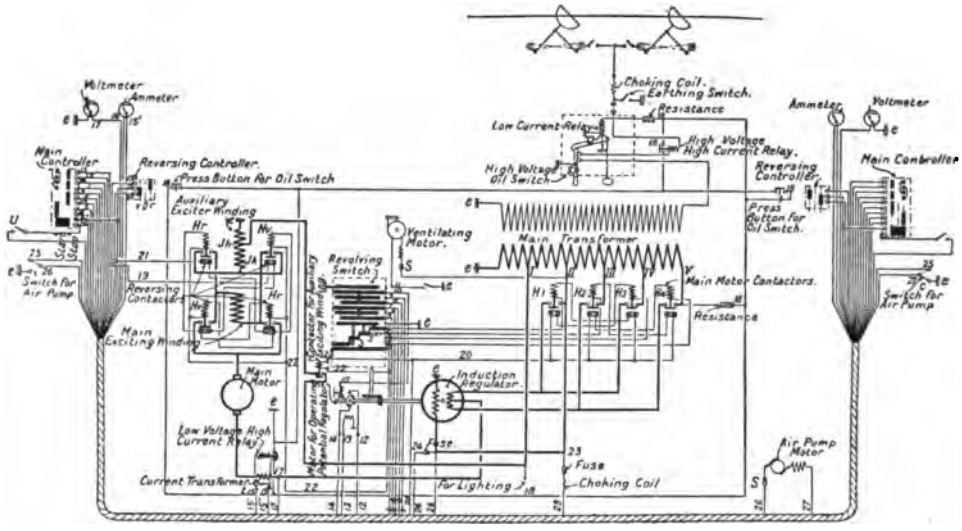


FIG. 139.—Connections for Siemens-Schuckert Passenger Locomotive.

a maximum value in the opposite direction by turning the movable element so as to complete the circle.

Now, from the diagram, Fig. 139, it can be seen that the first tapping I of the secondary of the main transformer runs direct to an intermediate point on the auxiliary exciting winding of the main motor, but the circuit may be broken by means of the auxiliary exciting winding contactor. But if we trace the other leads, II, III, IV and V, of the secondary winding of the main transformer, it will be found that each of these can be connected in series with the induction regulator by means of the main contactors. With regard to tapping II of the main transformer, it will be seen that this runs to the primary winding of the induction regulator, so that the latter is energised with a voltage corresponding to that across the two first stages of the secondary winding of the main transformer. Still confining our attention to the secondary lead II, it will be noted that when the main contactor H_1 closes, the current flows to the motor through the secondary winding of the induction regulator. It will also be seen that the lead leading to the motor is connected to the middle point of this winding.

Now, if when the contactor H_1 be closed the voltage of the induction regulator is *nil*, the pressure applied to the main motor would be that corresponding to tappings I and II, but matters are so arranged that at this instant the induction regulator is

producing between the middle point and one end of the secondary a pressure equal to half that across a secondary stage of the main transformer, and the direction of this pressure is such that it opposes the pressure due to the main transformer. Thus, at the instant when the contactor H_1 closes, the voltage applied to the terminals of the main motor is only equal to half that across the tappings in use.

The induction regulator is worked by a small single-phase motor. This is also geared to a revolving switch which supplies current to the main contactors one after the other. The connections between the main controller and this revolving switch are not easy to follow, but it can be seen that the contacts 1, 2, 3 and 4 on the revolving switch drum switch on and cut off current to the contactors H_1 to H_4, and that when the revolving switch turns in one direction the contactors will operate in the order 1 to 4, and when it turns in the opposite direction in the order 4 to 1. The other contacts on the revolving drum are connected up to the main controller.

When the driver moves the latter into the running position current flows through the top contacts of the revolving switch to the small single-phase motor, which serves to turn this switch and the induction regulator, the induction regulator and revolving switch being geared together. We have seen that at the instant when the contactor H_1 closes the induction regulator is developing a voltage equivalent to half that between the transformer tappings I, II, and that this voltage opposes that due to the transformer. But as the moving element of the induction regulator revolves its voltage is reduced and the pressure at the motor terminals therefore rises. When the movable member of the induction regulator is in a position which gives zero voltage, the pressure across the motor terminals is that between the secondary leads in use, since under those conditions the induction regulator is giving no opposing voltage. Further movement of the revolving element of the induction regulator causes the latter to build up a voltage in the opposite direction, so that the pressure of the induction regulator is now added to that between the secondary leads, and this voltage goes on increasing steadily until the voltage across the motor terminals rises to a value corresponding to one and a half that across a secondary stage, the extra or half stage pressure being supplied by the induction regulator. At this instant contactor H_2 closes and contactor H_1 opens, because the revolving switch above the induction regulator has now moved through the distance X, and consequently contactor H_2 is energised and contactor H_1 de-energised.

From the diagram it will now be seen that the transformer tapping III is now connected in series with the induction regulator. Since at the instant when contactor H_2 closed the induction regulator was developing a pressure corresponding to that across half a secondary stage, it might appear that the closing of contactor H_2 gives rise to a big jump in the voltage applied to the motor. But it can easily be seen that this is not so, for the connections are such that when contactor H_2 closes the voltage produced by the induction regulator opposes that of the transformer. This is evident from the diagram, which shows that contactor H_2 is connected to the opposite side of the induction regulator to contactor H_1. Thus, at the instant when contactor H_2 closes and H_1 opens, the voltage of the induction regulator opposes that of the secondary tapping III. As the movable element of the induction regulator continues to turn, the voltage produced by the regulator falls and ultimately drops to zero. It then builds up in the opposite direction, and assists the voltage due to the transformer.

When the pressure across the terminals of the induction regulator has attained a maximum value, contactor H_2 opens and contactor H_3 closes. This process continues until contactor H_4 closes, when the small motor which actuates the induction

regulator and revolving switch is brought to a standstill. When it is required to reduce the speed, the motor just referred to is run in the opposite direction, and the contactors then close in the opposite order and the voltage at the motor terminals is gradually reduced.

It will be gathered that the whole of the speed variation is effected by means of the main controller, which has four positions. Two of these are marked "Start" and "Stop," whilst the other two positions are indicated by plus and minus signs. When the controller handle is turned so that the plus position is reached, the voltage at the motor terminals is automatically increased by means of the contactors H_1 to H_4 and the induction regulator, and when the controller handle is turned to the minus position the voltage is reduced in the same manner. As soon as the motor is subjected to the full voltage, the small controlling motor stops, and the same applies when the voltage on the main motor is at its lowest value.

FIG. 140.—Driver's Compartment.

For feeding the small motor and the various contactors in the circuit, low-tension alternating current is used, and this is taken from the secondary windings of the main transformer. It will be gathered that with this arrangement only four main contactors are required, and that the whole control system is very simple. There are two controllers at each end of the locomotive; one is the main controller and the other the reversing controller. These are grouped together in the usual manner.

From the overhead wire, the current passes through both the current collectors and dividing switches to a choking coil, which latter protects the electrical equipment from excessive voltages. At one end of the choking coil an earthing switch is fixed. The current then passes through a maximum current relay to the high voltage oil switch, and from there it flows through the primary winding of the main transformer to earth. It will be gathered that the oil switch can be opened from the driver's compartment by pressing a button which completes a circuit through a coil associated with the oil switch.

As regards the secondary circuit, the main connections for this have already been referred to. But it may be pointed out that the secondary lead marked II, in addition to energising the primary member of the induction regulator, also supplies current to the ventilating motor which ventilates the induction regulator, etc., and, in addition, this lead carries the current for working the various contactors, as well as the air pump motor on the left of the diagram. The other secondary leads 3, 4, and 5 simply supply the main motor.

The main driving motor is placed in the middle of the locomotive, and on the front of this the four reversing contactors are fixed. These reversing contactors are,

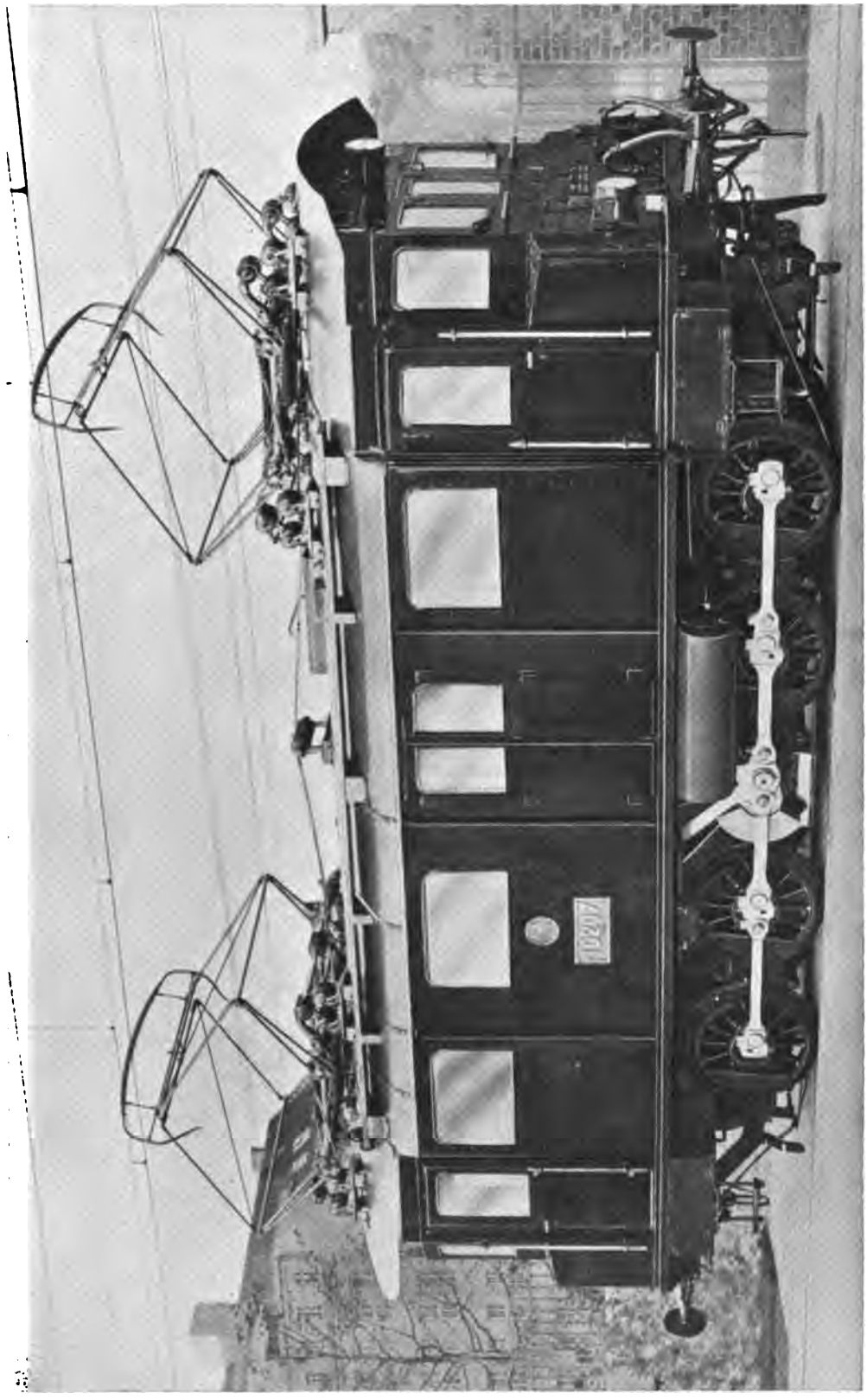


FIG. 141.—Siemens-Schuckert Goods Locomotive.

of course, operated by means of the reversing controller handle. The connections for these contactors are easily followed from the diagram, and it will be seen that their function is to reverse the current in the main and auxiliary windings of the motor. To reverse the direction of a series motor, we must either reverse the field or armature connections, and in the case of this locomotive the leads of the field system are reversed. In front of the motor the induction regulator is placed, and the main transformer is at the other end of the machine, the transformer being enclosed in a metal case.

The driver's compartment, which is shown in Fig. 140, is shut off from the machine compartment and can be electrically heated. From this illustration it will be observed that the main controller does not differ in appearance from the ordinary

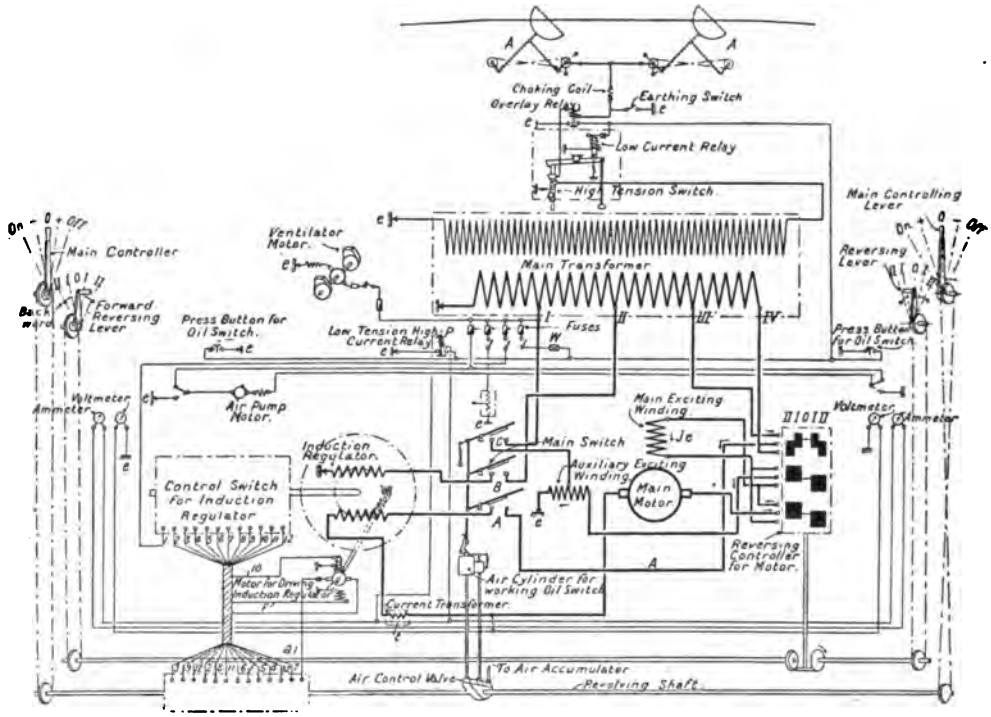


FIG. 142.—Connections for Siemens-Schuckert Goods Locomotive.

traction type. The brake control gear is to be seen on each side of the controller. Current and volt meters are placed directly in front of the controller, whilst compressed air gauges are shown in the upper part of the illustration. Other instruments and devices in the driver's compartment include a speed indicator, a pump switch, and sanding equipment. The button for opening the main oil switch is to be seen just under the current and volt meters. It is to be noted that this is only used for opening the main oil switch, and that the switch is closed by means of a lever fixed on the side of the wall of the high-tension chamber, and that this lever is operated by hand.

Turning now to the goods locomotive, Fig. 141, this has four coupled axles which are driven in a manner similar to that previously described by means of a single-phase motor, but in this instance the motor is not situated in the centre of the locomotive, as in the other case. The length of the wheel base in this case is 4·8 m., and that of the locomotive over the buffers 10·5 m. The locomotive weighs 64 tons,

the mechanical part accounting for 35·5 tons, and the electrical equipment 28·5 tons. Each driving axle is loaded with 16 tons. The bearing springs of each two neighbouring axles are connected together with equalising levers. At a speed of 32 km.—say, twenty miles—per hour the locomotive is capable of hauling a weight of 700 tons, including the locomotive, and a weight of 1,400 tons, including the locomotive, at 25 km.—say, fifteen and a half miles—per hour. In the first case the locomotive is capable of hauling the weight continuously, and in the second instance for a period of one hour. The greatest possible speed is 80 km.—fifty miles—per hour.

Westinghouse quick-brake equipment has been provided. The pressure on the eight wheel blocks amounts to 65 per cent. of the weight of the locomotive. Besides the

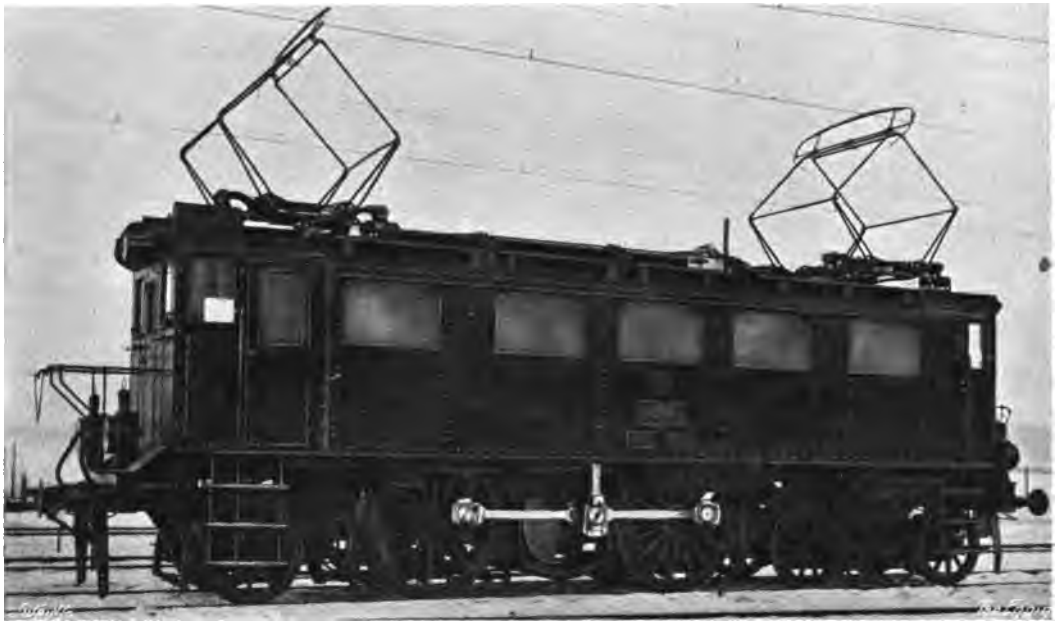


FIG. 143.—Bergmann Locomotive.

compressed air brake there is a counterweight lever hand brake which can be operated at each end of the driver's platform.

As in the case of the locomotive just described, the control is carried out by means of an induction regulator, but in this instance the regulator is only connected in series with one of the secondary stages. From an inspection of the diagram, Fig. 142, it can be seen that there are only three separate switches in the main motor circuit —a switch A for the main motor circuit, another B for the primary of the potential regulator, and a third C for the auxiliary winding of the motor. These are pneumatically operated. All the other heavy current switches are opened and closed by hand and are revolving switches.

On each of the driver's platforms there are two controlling levers, one of which is used for changing the direction and the voltage stages of the main transformer, and the other for controlling the potential regulator. The latter is done in the three middle positions, whilst in the end positions the control lever switches the three switches A, B, C on or off, as the case may be. This, it is to be observed, is done with compressed air. Both levers are bolted opposite one another in such a manner that the induction

regulator cannot be controlled until after the direction switch has been adjusted and the main switches A, B, C have been closed. The motor shown in Fig. 138 belongs to this locomotive. As for the remainder of the electrical equipment, this corresponds to that of the passenger locomotive previously described. But it should be mentioned that the controlling levers are duplicated, so that the driver can control the locomotive from either side, this being an advantage when shunting, since the driver can then manipulate the levers when taking a view from either of the side windows.

We will now pass on to a locomotive constructed by the Bergmann Electrical Company, the London agents being the Adnil Electric Company, Ltd. This engine, shown in Fig. 143, is now in every-day use. The length over the buffers is 12·5 m. (41 ft.), the length of the body 10·26 m. (33 ft. 8 in.), the width 3·05 m. (10 ft.),

FIG. 144.—Bergmann Locomotive (End View).

FIG. 145.—Driver's Compartment.

and the height 3·820 m. (12 ft. 7 in.). The driving wheels are 1·126 m. (5 ft. 4 in.) in diameter, whilst that of the bogie wheels is 1·013 m. (3 ft. 4 in.). The makers point out that steam express locomotives of similar output as used on British main lines have an overall length including tender of about 18·29 m. (60 ft.), and the total weight, including coal and water, is considerably over 100 tons, whereas the weight of this electric locomotive is about 72 tons. An end view of the locomotive is given in Fig. 144, and a view of the interior of the driver's compartment in Fig. 145. So far as the external appearance is concerned, and the method of transmitting the power from the motor to the driving wheels, the engine does not differ appreciably from the other locomotives which have been constructed for the Dessau-Bitterfeld Railway. The electrical equipment, however, is of considerable interest, and possesses one very novel feature. The novelty lies in the fact that, although the locomotive is fitted with a series motor, control is effected by

shifting the brushes. The system of controlling single-phase locomotives by brush shifting is, of course, quite usual when Déri motors are employed, but up to the time of the appearance of the locomotive now under consideration, no endeavour appears to have been made to vary the speed by brush shifting with series motors.

It would appear that any attempt to obtain speed variation in a series motor by displacing the brushes from the normal working position would result in bad sparking, but the difficulty has been overcome by adopting a special arrangement of the compensating winding. Hitherto the compensating coils of each pole have been connected up in series, but in the Bergmann motor they are connected in parallel. Suppose that in the face of a given pole there are six slots, as shown in Fig. 146, then the compensating winding of each pole consists of three coils of which the innermost is wound in the slots so as to enclose one tooth, the middle three teeth and the outer five teeth, all these coils being connected in parallel. By accurate calculation of the number of turns, taking into account the ohmic resistance, leakage coefficients, etc., it has been possible by this winding to develop in the commutation zone a suitable commutating or reversal field for all positions of the brushes, and brush regulation can therefore be adopted.

It is well known that by providing an ordinary direct-current motor with interpoles it is often possible, with a given size machine, to get better results than can be secured with a motor that is not provided with interpoles. In view of the very complete compensation which this new compensating winding provides, the Bergmann Company claims that the motor is capable of developing a large output for its size. A test carried out with one of these motors demonstrated that the distribution of the total current varies in the individual coils when the brushes are displaced, and by suitable allocation of the windings it is possible to arrange that the current so varies over the different coils that a good reversing field always exists in the brush line of commutation, so that sparkless commutation can be secured at all loads and speeds.

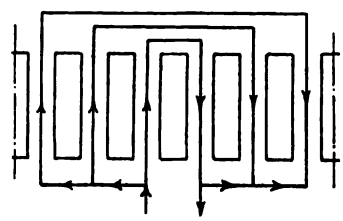


FIG. 146.—Arrangement of Compensating Windings.

By adopting several voltage steps in conjunction with this system of brush displacement a very satisfactory system of control has been secured. At starting the motor is switched on to the lowest voltage and the brushes are gradually rocked forward. They are afterwards quickly brought back to the original position and the next voltage step is then brought into use, when the brushes are again rocked forward, and so on until the maximum voltage is reached. By this method the current consumption at starting is kept down to a low value. Moreover, owing to the absence of an induction regulator, the power factor can be maintained at a high value. The curves, Fig. 147, relate to a 2,000-h.p. Bergmann single-phase motor started on this principle. These curves have been plotted on the basis of a constant current of 4,000 amperes, and show the relation of speed, output, etc., to the angle of displacement of the brushes. The curves relate to a motor designed for a periodicity of fifteen cycles per second and the voltage steps are 250, 375, and 500. It should be explained that the constant current is due to the fact that although the current increases by rocking the brushes forward it drops a corresponding amount with the increase in speed of the motor. Another point worthy of note in connection with this system is that when changing the voltages the brushes are shifted back before the circuit is broken, so that the current is first of all reduced.

It will readily be understood that by rocking the brushes in the manner described a uniform acceleration is obtained, and that it eliminates sudden jumps. In order that the amount of power required for shifting the brushes may be reduced to a minimum the parts are made to work with the smallest amount of friction possible. The brush ring is mounted in ball bearings. Moreover the displacement of the brushes over the periphery of the commutator only amounts to about 2 in. A special brush rocking gear is adopted, which may be operated from the driver's cab by turning a handle continuously in one direction throughout the entire speed regulation period, and the process of turning this hand wheel moves the brushes backwards and forwards. The hand wheel used for moving the brushes is to be seen in Fig. 145. In order that the path of displacement of the brushes may be shortened as much as possible so as to accelerate reversal, a small auxiliary winding is provided in the motor which from the start advances the position of the field axis, and when reversal takes place this winding has to be changed over. This is effected when no current is passing and before the motor is switched into circuit by means of an ordinary reversing switch, which is coupled up with and actuated from the main brush rocking gear and with the aid of the hand wheel already referred to.

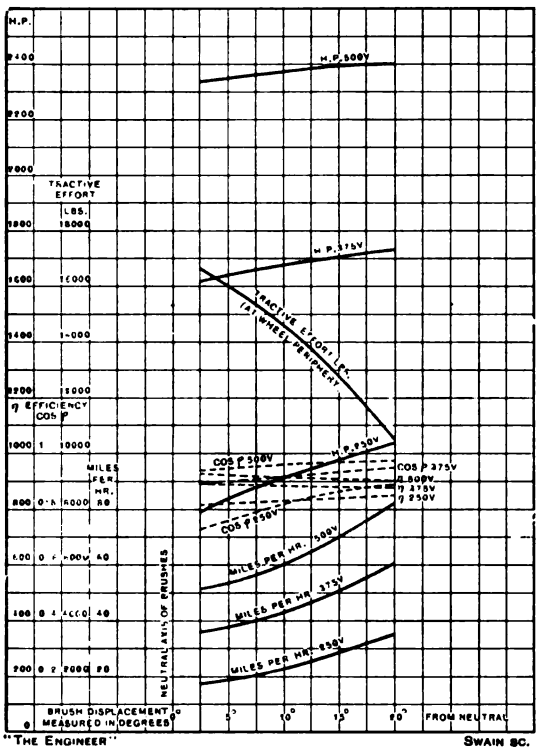


FIG. 147.—Performance Curves.

The first turn of the hand wheel operates the reversing switch. Next, the current is supplied to the motor through a main switch, and afterwards the brushes are shifted in the manner already described. First of all, the lowest voltage is applied to the motor terminals, and the brushes are slowly rocked forward from the neutral axis to the working axis for maximum speed at that particular voltage. They are then quickly brought back to the first position, and the next voltage step is brought into use when the brushes are again rocked forward until the maximum speed is attained. Contactor switches actuated by compressed air are employed for bringing the various transformer tappings into use. The direction of revolution of the motor is dependent upon the direction in which the controlling handle is turned.

The drive is effected by cranks, connecting-rods and an intermediate jack shaft. Push buttons are fitted in the driver's cabs, by means of which the oil switch which controls the main transformer may be opened. The switch is closed in the usual manner. For the supply of compressed air a compressor is provided which is driven by a small single-phase commutator motor. The usual ammeters, voltmeters and air indicators are also fitted in the driver's compartments.

When the main motor is running at its normal speed, viz., 270 revolutions per minute, the locomotive runs at about 80 km. (50 miles) per hour, and develops at

the draw-bar a tractive effort of about 4,490 kg. (9,900 lb.). On an official test a maximum tractive effort of 36,300 lb. on the draw-bar was registered when the locomotive was stationary, and at this figure the wheels began to slip. As already explained, the total weight of the locomotive is 72 tons. The electrical equipment accounts for 26·5 tons, the motor 15·5 tons, and the transformer 7·6 tons. When the brushes are in the advanced position and when 50 amperes are passing into the high-tension side of the 10,000-volt transformer, the locomotive draws a passenger train weighing about 300 tons. At full speed and load the current taken on the high-tension side of the transformer is about 125 amperes, and about 5,000 amperes are supplied to the motor. The average impressed pressure amounts to about 270 volts at the motor terminals when the train is running at full speed.

There was once a considerable difference of opinion among electrical manufacturers who have taken up this question of single-phase working as to the relative advantage of series motors and repulsion machines, but the majority now seem to favour the series motor. The Bergmann Company points out that the ordinary repulsion motor works best at about 70 per cent. of the synchronous speed, whereas the speed of the series motor can be increased far beyond the synchronous value.

From the foregoing it will be seen that considerable progress is being made with the single-phase system in Germany, and it is pretty safe to assume that other important developments will be made in the near future. For instance, it has been decided to electrify the Berlin Stadtbahn. This railway, which runs through the principal parts of Berlin and its suburbs, was put into operation on January 1st, 1872, and judging from a report submitted by the Railway Ministry to the Prussian Diet, it has proved highly successful so far as its passenger traffic is concerned. It appears that in 1895 75,000,000 passengers were carried over the inner circle, whilst in 1909 the number had increased to 157,000,000. The traffic on the suburban sections has also increased in a like manner, the number of passengers carried in the two years just mentioned being 41,000,000 and 137,000,000 respectively.

The report shows that the population of Berlin itself which is served by the inner circle lines has increased from 2,017,000 to 2,898,000 during the period just referred to, and that the population of the suburbs has risen by about 425,000. It is not surprising, therefore, that the capacity of the Berlin Stadtbahn has become altogether inadequate to meet present-day requirements. Various suggestions have been put forward to overcome the difficulties now met with in dealing with the traffic, and these include doubling the existing lines, building new tube railways, and electrifying the present system. But owing to the great financial and other difficulties involved, the latter scheme has been recommended and in the single-phase system is considered most suitable. Electric locomotives will probably be used to a considerable extent, since it is desired to retain some of the old rolling stock. It has been proposed to order 557 electric locomotives, 690 passenger coaches, and 29 repair cars. Two or more locomotives would be coupled to the same train, as circumstances demand, and operated by one man by means of a simplified multiple unit system. Experience gained with electric locomotives in Germany goes to show that the maintenance costs are below those of motor coaches, and various other advantages are also secured. Locomotives can be built with very large hauling powers, and one such engine can therefore take the place of many motor coaches. Added to this, the motor and other electrical gear are very accessible, which is an important item from the points of view of cleaning and repairs.

Experience gained in Germany indicates that since the motors of electric locomotives are spring borne and placed high up in the body, there is little noise and

vibration. During the busiest hours of the day, when the traffic is heaviest, the trains would be made up of thirteen six-wheel coaches, and propelled by two locomotives, one at each end of the train. At other times, when the railway is less busy, the trains would consist of five or eight coaches, coupled to a single locomotive. Trains made up in this manner could be driven from either end by fitting the last coach with a controller, which would naturally be put into communication with the motors in the locomotive The weight of a train composed of thirteen coaches and two locomotives would be 355·5 tons, which is 28 per cent. more than that of the heaviest steam train now at work on this railway. The great advantage which the electrical system would present is naturally the rapid acceleration, and this, of course, is one of the main reasons for electrifying lines such as that under consideration.

The pressure is to be 15,000 volts and the periodicity $16\frac{2}{3}$ cycles per second.

THE MURNAU-OBERAMMERGAU RAILWAY

THE Murnau-Oberammergau Railway was one of the first railways to be electrified on the single-phase system. When in the year 1904 the Munich local railway company decided to adopt electric traction a great deal of consideration was given to the question of the proper system to use. One of the fundamental requirements was that the maximum power used should be as small as possible, because of the limited water power available at the generating station. It was suggested that three-phase current motors should be used on the trains and arranged for cascade control or for working with a variable number of poles, but neither of these schemes was considered satisfactory from a technical or financial standpoint. But the chief reason for abandoning the idea of using the three-phase system was the difficulty of providing a satisfactory overhead system on the sidings.

There is a large number of sidings, and it was feared that the cost of the

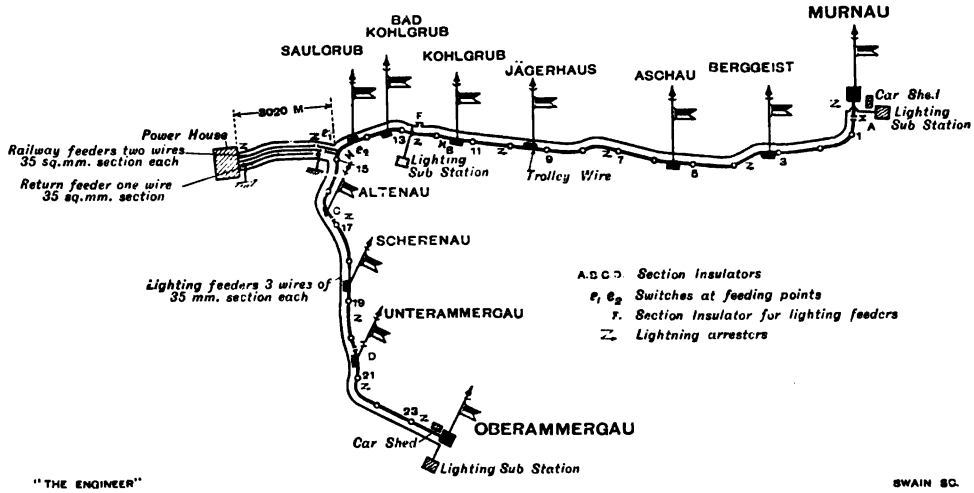


FIG. 148.—Map of the Murnau-Oberammergau Railway.

overhead construction would not only be high, but that it would also prove expensive to maintain. The continuous-current system presented the following advantages :— The motors have the desired series characteristics ; the cost of the coach equipment is low, and the overhead construction at the points and crossings simple. On the other hand, the losses in the cables and sub-stations, and particularly the running costs of the latter, rendered the system unsuitable. Finally, the single-phase system was considered, employing alternating current at 5,000 volts pressure and at a periodicity of 16 cycles per second, and this proved to be the best for this particular railway. Moreover, the power required for working the railway was found to be lower than that needed by either of the other systems, notwithstanding the greater weight of the coach equipment. This is owing to the small transmission and other losses. Single-phase motors are just as suitable for varying gradients as the direct-current machines, and the greater cost of the electrical equipments on the alternating-current

trains is more than balanced by the saving in the transmission and distribution circuits.

The line is 26·6 km. long, and runs through mountainous country with gradients

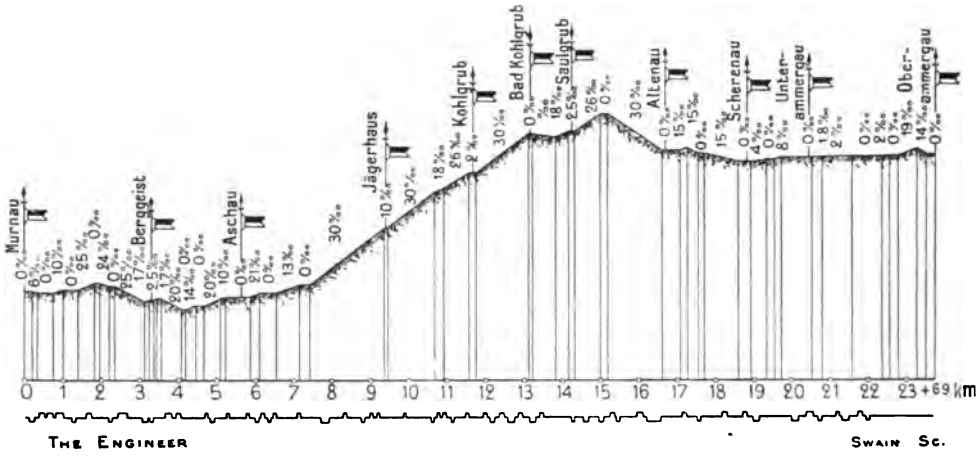


FIG. 149.—Profile of Line.

up to 1 in 33. It deals with a considerable passenger and goods traffic. The difference in level between the ends of the line amounts to 327 m., and there are numerous curves on the heaviest gradients. Figs. 148 and 149 give a map and profile

FIG. 150.—Overhead Construction with Wooden and Lattice Poles.

of the line respectively. The schedule time for the journey from Murnau to Oberammergau is 72 minutes, and the return journey is covered in 65 minutes. In both

FIG. 151.—Catenary Overhead Construction.

cases the time occupied in stopping at the eight intermediate stations is included in these figures. Taking the time occupied in stopping into account, the speed is

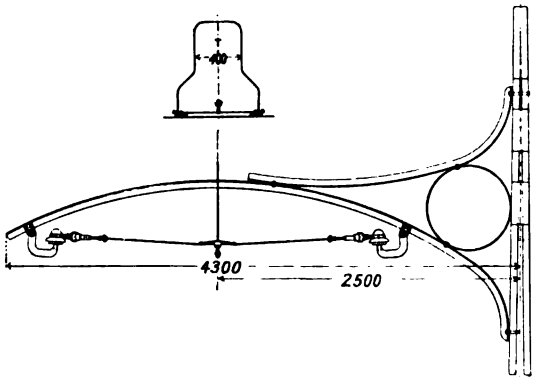


FIG. 152.—Bracket Arm.

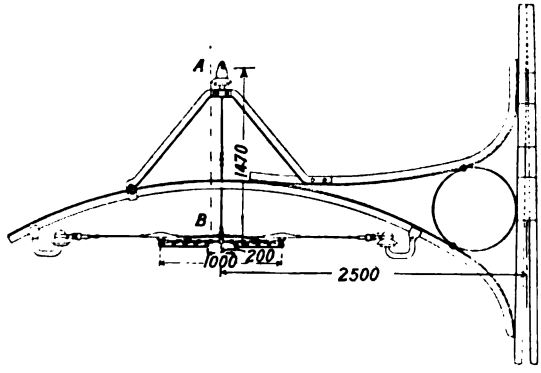


FIG. 153.—Bracket Arm.

19·6 km. per hour when the train is running up hill and 21·6 km. when travelling down hill. The maximum speed on the level or down hill is 40 km. per hour. In the winter there are usually twelve trains daily, and in the summer sixteen trains for passengers and goods, but additional trains are put into service if required.

The power station contains two 500 h.p. and two 30 h.p. water turbines. They are supplied with water from the river Ammer. The two large turbines are fitted with heavy fly-wheels, and each is coupled to two generators, one for supplying power to the railway and the other for lighting. Each of the traction machines has a capacity of 280 kw., and generates single-phase current at a pressure of 5,500 volts, and at a periodicity of sixteen periods, with a power factor of ·8. The lighting generators are capable of giving a continuous output of 150 kw. at ·9 power factor, and work at a pressure of 5,000 volts and at a periodicity of 40 cycles. All the generators were built by Siemens-Schuckert. The two 30 h.p. turbines are coupled to continuous-current machines for exciting the main generators and for lighting the power station and dwelling-houses of the staff. The three-phase lighting dynamos supply current to rotary converters at Murnau, Kohlgrub, and Oberammergau, and also a small amount of power to a few other points.

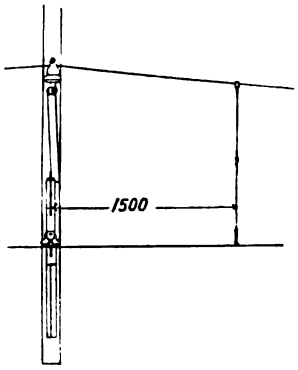


FIG. 154.—Section on A B in Fig. 153.

The lighting feeders are carried on petticoat insulators mounted on the wooden

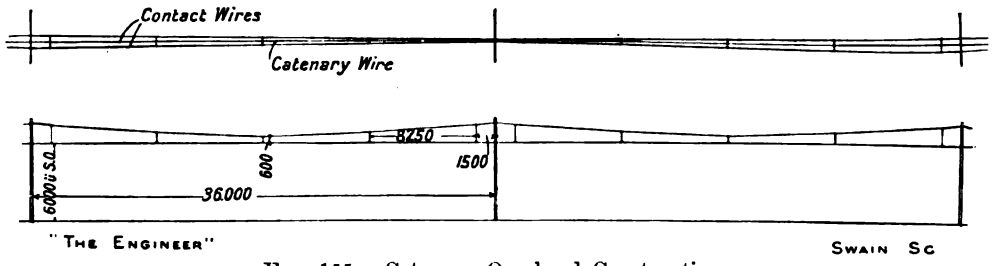


FIG. 155.—Catenary Overhead Construction.

poles that support the contact wire. These feeders consist of six wires of 35 sq. mm. section, three of which go to Oberammergau and three to Murnau. The railway

FIG. 156.—Motor Coach and Trailer.

FIG. 157.—Station at Oberammergau.

feeders, on the other hand, consist of two wires of 35 sq. mm. section. These two wires are connected in parallel, and constitute the outgoing feeder, and one wire of the same size is earthed at Kammerl and Saulgrub, and this forms the return feeder. At Saulgrub the connection is made to the trolley wires going to Oberammergau and Murnau. The overhead conductor takes the form of a round copper wire of 50 sq. mm. section. For the greater part of the distance the contact wire is carried on wrought iron brackets, some of which are fixed to wooden poles and others to wrought iron lattice poles. The latter are used on curves and in railway stations. This type of construction is shown in Figs. 150 and 151, and details of one of the bracket arms are shown in Fig. 152. The distance between the bracket poles on the straight sections of the railway is 35 m., and on the curves 30 m. The metal poles are well earthed. In addition to the insulator between the cross-wires and the contact line, insulators are also interposed at the ends of the cross-wires as shown in Fig. 152.

One section of the line, as shown in Fig. 151, was equipped with Siemens

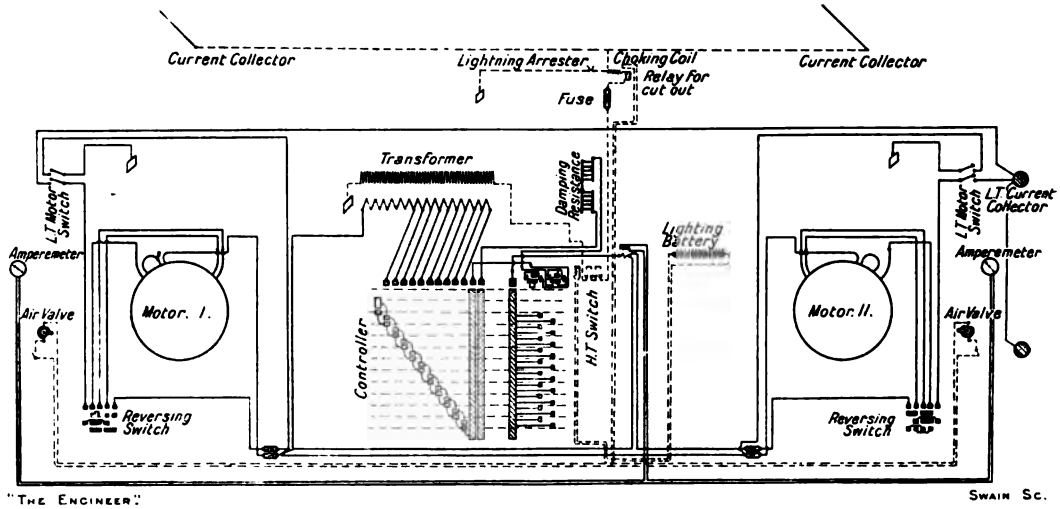


Fig. 158.—Motor Coach Connections.

catenary suspension system for the purpose of experiment. This is the same equipment as used on the Cologne-Bonn Railway, which is a 1,000-volt continuous-current line. Details of the system are given in Figs. 153, 154, 155. There are two trolley wires, and these are supported by cross bars hung from a strong steel catenary cable which is suspended over the line on insulators. The cross bars can rotate round their point of support and are of different lengths, so that the two trolley wires alternately approach and recede from one another, as shown in Fig. 155. At the points where the contact wires are closest together and farthest apart the cross bars are anchored to the poles by special span wires to prevent wind or bow pressure causing side motion. This zigzag arrangement of the wires also ensures uniform wear on the bow collectors. The trolley wires can move up or down independently owing to the pivoted suspension of the cross bar, so that both wires always keep in contact with the bow even when the latter is tipped up by the superelevation of the rails on curves. This arrangement has been found to eliminate arcing between the bows and the overhead wire. The wires are prevented from moving sideways. To ensure safety in the event of a wire breaking earthing arrangements are employed at

all the stations and level crossings. In the event of a wire breaking it is immediately earthed

The trolley wire is divided into five sections, but under normal conditions they are connected together. There is no interruption in the supply when the bow passes from one section of the contact wire to the other. Moreover, there is no risk of momentarily connecting any section that is switched off to a live section through the bow, as the latter passes over it. The overhead lines are protected against lightning by horn type arresters, which are fitted at various points along the line (see map, Fig. 148). The rails are bonded by means of copper wires having a diameter of 10 mm., the bonds being riveted to the rails by means of iron rivets. Cross bonds are also provided at points 100 mm. apart. The voltage drop when a 55-ton train is taking 30 amperes, running at the farthest part from the power station, viz., Murnau, is 210 volts, or about 3·8 per cent. of the working pressure. If, however, two trains happen to start together at this point, the drop then amounts to 7·6 per cent. of the working pressure.

Turning now to the rolling stock, it has been indicated that the passenger traffic

FIG. 159.—Motor Coach taking Current from Low-tension Wire.

is less in the winter than in the summer. On the other hand, the goods traffic is more heavy in the winter. To meet these conditions two different types of coaches were built for use in the two seasons. The coaches which were built for winter service are divided into second and third class compartments, the former containing eight seats and the latter twenty seats. There are also postal and luggage compartments. These coaches weigh about 60 tons and are capable of carrying 24 tons. For the summer traffic, on the other hand, coaches have been built for passengers only, these having sixteen second-class seats and thirty third-class seats. These coaches weigh 27·5 tons. A train composed of a motor coach and a trailer coach is shown in Fig. 156 and a train at the Oberammergau Station in Fig. 157.

The trains are made up according to requirements, with a special post and parcel coach and one or two passenger or goods trailers, such trains being capable of carrying from 100 to 150 persons. Four motor coaches of this type were supplied to begin with. The coaches are of the Nürnberg Maschinenbau-Aktiengesellschaft three-axle type.

The motor coaches, trailers, and post coaches are all fitted with Westinghouse automatic brakes. There are two driver's compartments to each motor coach, and these are partitioned off from the passengers' compartments. All the motor and trailer coaches are electrically lighted and heated. Fig. 158 gives the electrical connections for a motor coach. The two bows are connected to a common conductor supported on porcelain insulators. It will be noted that the high voltage circuit is connected to a horn lightning arrester, then through an overload relay and fuse fixed on the roof of the coach, and finally the main conductor passes through a porcelain insulator and down the centre of an earthed brass pipe to the high voltage main switch. The latter is naturally connected to the primary winding of the transformer. The secondary winding of the latter is divided into eight sections, each giving about 17·5 volts. These are connected to the motors through a reversing switch and barrel controller.

In the coach sheds at Murnau and Oberammergau arrangements are made for

FIG. 160.—Controller, etc., under a Motor Coach.

supplying low-tension current to the motors on the coaches. At the end of the coaches there is a plug which takes a portable current collector, as shown in Fig. 159. Switches are fitted in the driver's compartments for cutting either of the main motors at will. When the coaches are running over the high-tension lines the low-tension current collector is removed. Two bow current collectors are fitted to each motor coach, and they are raised and lowered by compressed air. The controller to be seen in the middle of the illustration, Fig. 160, consists of a main barrel fitted with a double row of sliding contacts which pass under corresponding finger contacts. The circuit, however, is finally broken by means of an auxiliary drum fitted on the same shaft as the main drum and provided with magnetic blow-out gear. One of the single-phase motors as used in the motor coaches is shown in Fig. 161. They are series wound machines provided with compensating windings and designed for a working pressure of 276 volts. They were tested with a load of 100 h.p. for one hour, when the temperature rise was found to be 65° Cent. The machines were also found to

have a high power factor. It is also worthy of mention that although this railway was put into operation at a time when single-phase working was in its infancy, the

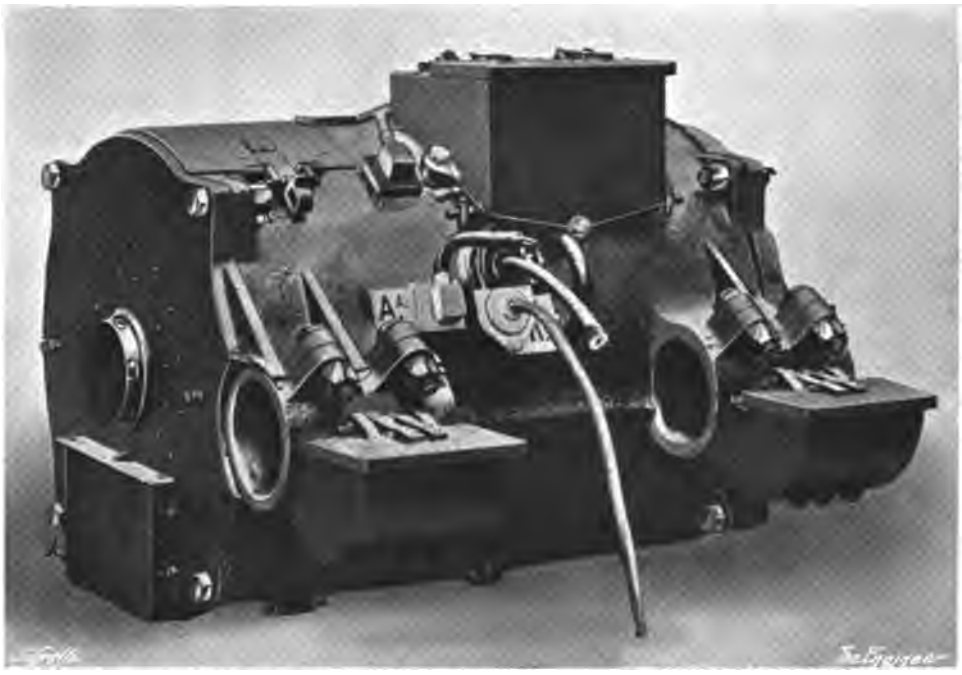


FIG. 161.—Single-Phase Motor.

commutation of the motors proved excellent notwithstanding the wide variations of load caused by the heavy gradients and the large amount of shunting that has to be carried out.

THE MITTENWALD RAILWAY

THE opening of the first section of the Mittenwald Electric Railway took place on October 28th, 1912. This is the eastern section which extends from Innsbruck to Scharnitz and passes through the Tyrol. The length of the line is 33 km. The complete railway will provide connections between Innsbruck, Scharnitz, Garmisch, Partenkirchen, Griessen and Reutte. The western section—see map, Fig. 162—extends from Reutte to Griessen, a distance of 32 km. Between these lines there is the Scharnitz-Garmisch-Partenkirchen-Griessen section, which passes through Bavaria. All these lines are to be worked with single-phase alternating current. As far back

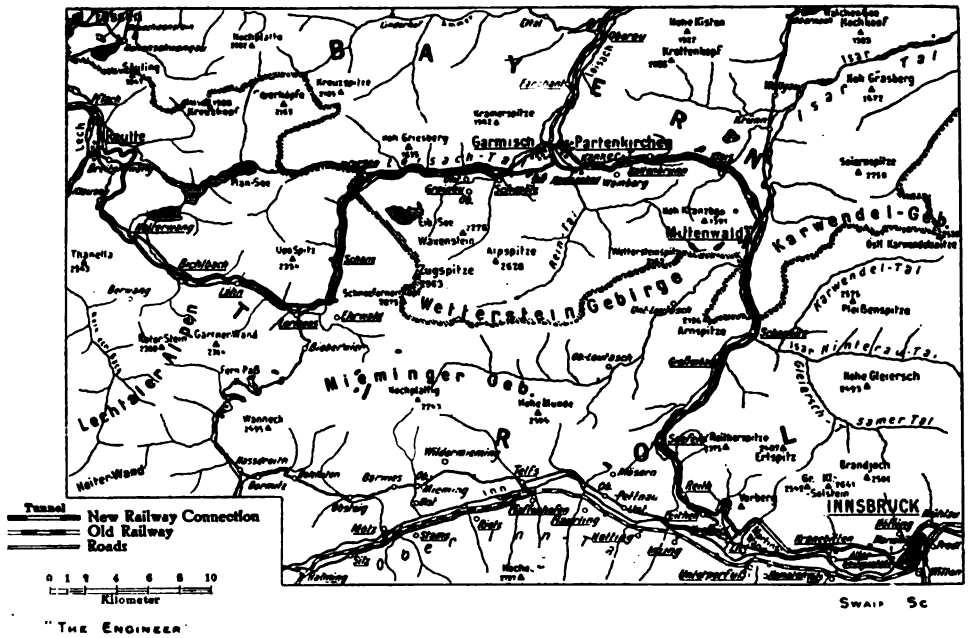


FIG. 162.—The Mittenwald Electric Railway.

as August 17th, 1889, an electric light works was started for the supply of electricity to Innsbruck. It was originally equipped with two Ganz alternators, each rated at 80 kw. The plant was designed for supplying current to 1,300 16 candle-power lamps burning simultaneously. This hydro station, which is worked by the falls of the Wurmbach to the north of Innsbruck, is still in operation. An 80 kilovolt-ampere alternator, two 200 kilovolt-ampere single-phase alternators, and two 1,200 kilovolt-ampere two-phase alternators were added in 1909, and a new station situated in the south of Innsbruck on the Brenner, close to the Stefansbrücke, was started in 1903. This latter station utilises the waters of the river Sill. Originally it contained two 2,500-kilovolt-ampere two-phase sets designed for a working pressure of 10,000 volts. Four additional machines, each capable of developing 3,300 kilovolt-amperes,

have since been added by the A.E.G. Union of Vienna. The total capacity of the Sill station is therefore at present 18,200 kilovolt-amperes. Clearly the use of electricity

FIG. 163.—Entrance to Tunnel 1,787 Metres long.

in this part has made remarkable headway. Since the end of 1911, 730 motors with a total output of 3,950 horse-power have been put down in the town of Innsbruck.

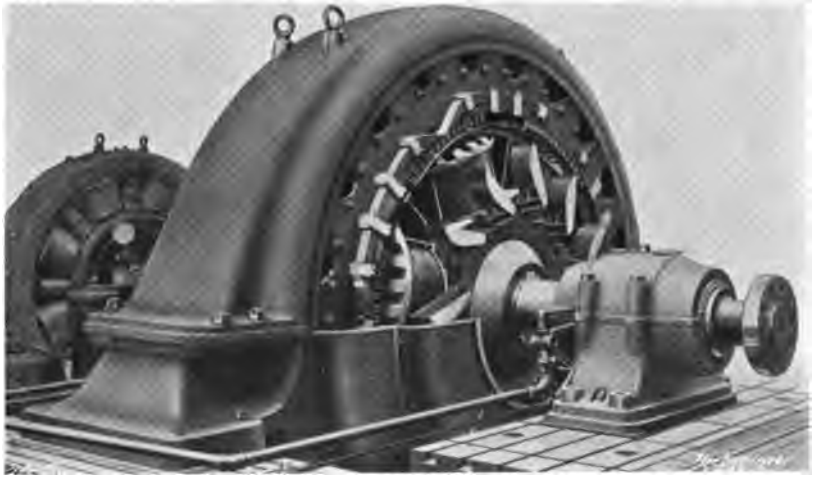


FIG. 164.—3,000-Kilovolt-Ampere Single-Phase Generator.

No fewer than 90,000 incandescent lamps and 480 arc lamps have also been added during the same period.

In 1904 the Stubaital Railway was built, this being the first single-phase mountain railway. It is supplied with current from the Sill station. A street tramway in Innsbruck is worked with direct current at a pressure of 500 volts, this current being

obtained from converters connected to the 2,000 volt two-phase mains. At the end of 1911 there were 18 km. of single track connected with the Innsbruck tramways. The owners of these tramways have also electrified the overhead line to Hall, which was originally worked by steam. When it was decided to electrify the line the direct-current system working at a pressure of 1,100 volts was chosen, this being the first railway in Austria to use high-tension direct current. An electrically operated rope railway also leads up to a sharp rise on the slopes of the northern chain of hills to the Hungerburg Plateau about 300 km. above Innsbruck. By reason of the beautiful view which is obtained at this altitude the line is well patronised by visitors during the summer months. The construction of the railway also arouses a great deal of interest.

FIG. 165.—Field Hub.

From the foregoing it will be seen that electricity was extensively used in Innsbruck itself and in the surrounding country before it came to be employed on the Mittenwald Railway. The work that has recently been carried out on this latter line is of an important and interesting character. The line is notable for the beautiful alpine scenery which it reveals to the traveller. On the Austrian sections, viz., Innsbruck to Scharnitz, a distance of 32·7 km., and Reutte to Griessen, a distance of 30·3 km., where the most magnificent scenery is met with, there are 18 tunnels, representing a total length of 4,305 m. One tunnel alone, the entrance to which is shown in Fig. 163, has a length of no less than 1,787 m. A number of viaducts and bridges also had to be built, and altogether the construction on the railway involved some very difficult work. Electrical working was found to present many advantages as compared with steam. The absence of smoke in the tunnels was an important consideration, and, moreover, in the construction of the line itself a gradient of 3·64 per cent., was permissible by using electric traction. The line reaches a height of 1,185 m. above the sea level at Seefeld, and in a distance of 21·2 km. a difference of level of 600 m. has to be dealt with. Had steam locomotives been employed it would have been necessary to lengthen the line by at least 4 km. just at the point where the greatest difficulties would have been met with. The saving introduced by adopting electric traction amounts to more than the total cost of the electrical

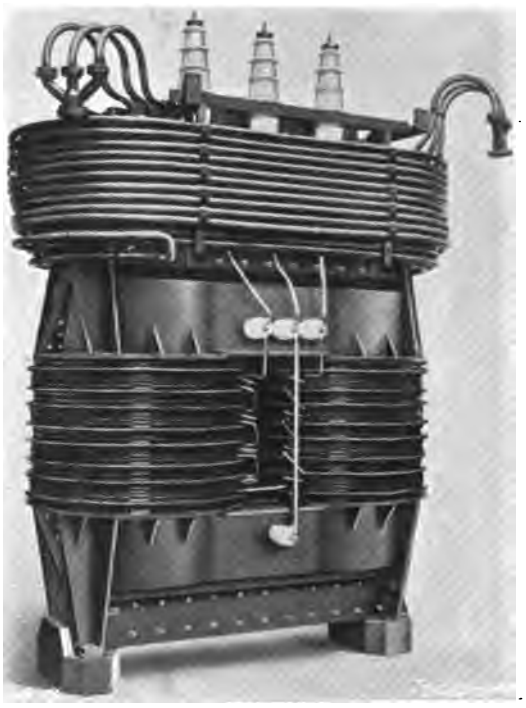


FIG. 166.—50,000-Volt Step-up Transformer.

equipment. Electric working is also advantageous on account of the water power available.

The power station for the Mittenwald Railway has been erected about 6 km. to the south of Innsbruck in the vicinity of the Sill works, and utilises the water power of the Ruetzbach, a river close to the Sill. The effective fall is approximately 185 m. At present there are two 4,000 h.p. Voith Pelton turbines in the Ruetz power station. Each of these is coupled to a 3,000 kilovolt-ampere single-phase generator, as shown in Fig. 164. These generators work at a pressure of 3,000 volts and at a periodicity of 15 cycles per second. They are capable of developing a maximum output of 4,000 kilovolt-amperes. Since the speed of the sets is 300 revolutions and the periodicity 15 cycles per second, the generators are six-pole machines. The cost is somewhat

FIG. 167.—Transporting a Transformer to the Ruetz Works.

higher than that of a four-pole machine, but the lower speed enables the pole core to be fixed with absolute rigidity to the rotor hub. By reason of the heavy weight of the poles very considerable centrifugal forces have to be dealt with. The weight of a wound pole is 3,540 kilos., and the fixing of the rotor hub, as shown in Fig. 165, is subjected to a centrifugal force of 343,000 kilos. at normal speed. At 80 per cent. excess speed it is increased to 1,000,000 kilos. From the illustration, Fig. 164, it will be seen that the magnets are fitted with fans for the purpose of ventilating the machine. By this means it has been found possible to keep the temperature rise well below the specified limit. It might appear that generators fitted with such large fans would be noisy, but this is not the case. Current derived from the generators is fed into transformers of the type shown in Fig. 166, and in this manner the pressure increased from 3,000 volts to 50,000 volts. The illustration, Fig. 166, shows the transformer removed from its case. Each generator is provided with an independent transformer, thus obviating the necessity of using 3,000 volt bus

bars and switches. These oil transformers, with water circulation, are designed for the same maximum rating as the generators, but the continuous rating is 1,800 kilovolt-amperes. The transformers are of the core type, with disc windings. The wound cores weigh 23 tons, and, owing to the nature of the ground, considerable difficulty was encountered in transporting them to their destination. This will be appreciated from Fig. 167. The 50,000-volt switches are placed in spacious cement cells. All these switches are fitted with electro-magnetic remote control gear, so that they can be operated from the switchboard in the main machine room. Automatic overload releases with time limit gear are fitted to the high-tension switches. The usual lightning arresters, etc., are also provided. Current at 50,000 volts is supplied by means of a high-tension line to two sub-

FIG. 168.—Transmission Line and Contact Wire on Track.

FIG. 169.—Transmission Line Passing Over Tunnel.

stations, where the pressure is lowered to 15,000 volts for use on the line. These sub-stations, which will also supply current to the Bavarian lines until the completion of a generating station at Walchensee, are erected at Reith and Schanz. The former place is 19 km. from the eastern boundary of Austria, and the latter 3·3 km. from the western boundary. Views of the transmission line, which is mainly carried on the same poles that support the contact wire of the railway, are given in Figs. 163, 168 and 169. Each of the transmission wires has a section of 35 square millimetres.

Separate poles for the transmission line are used between the power station and the railway line, a distance of about 6 km. The first section of the 50,000-volt. line passes through a desolate district, which is not easily reached in the winter months. On this account three wires are used on this section of the line, one of which serves as a spare. A copper lightning conductor is mounted above the high-tension line

FIG. 170.—Scharnitz Station.

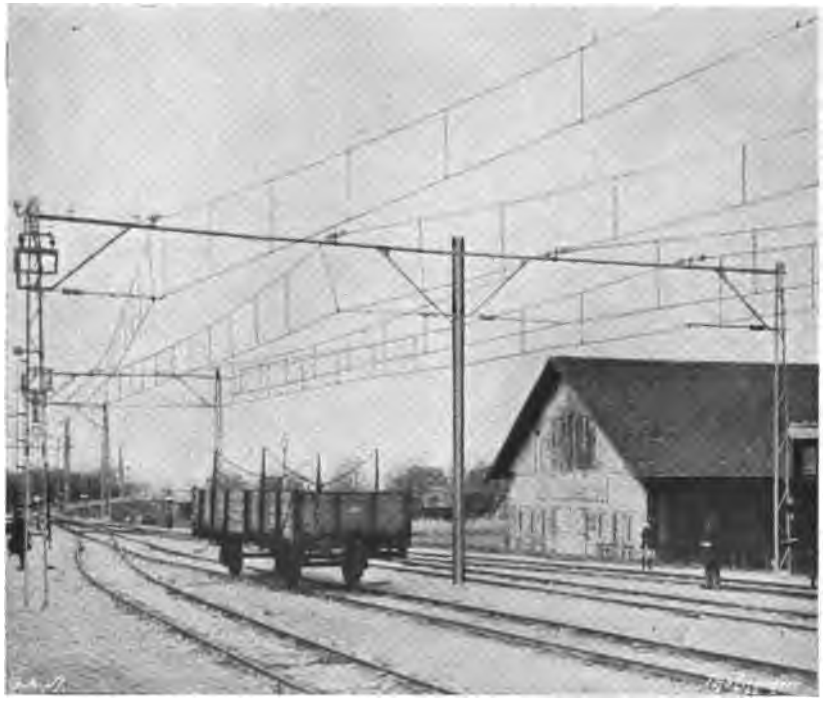


FIG. 171.—Shunting Station at Wilten.

FIG. 172.—Arrangement of Contact Line in Tunnel.

FIG. 173.—Train at Hochzirl Station.

on the top of each mast, this being carefully earthed at the basis of the masts. The masts, which are of the lattice type, are erected 80 m. apart. Separate masts for the transmission line are also used for a short distance on the Innsbruck-Scharnitz section, owing to the number of long tunnels. The erection of a high-tension line on the same masts that carry the contact wire for the railway introduces various difficulties which do not arise when a transmission line has its own supports. Obviously, the route is confined to that of the railway track, and in the present case a number of sharp curves, such as shown in Fig. 168, had to be negotiated. Moreover, the masts are subjected to vibration arising from the passage of the current collector. Experiment proved the link disc suspension insulator to be the only type suitable for use under these conditions. Experience gained in America has also led to this conclusion, but, owing to the climatic conditions met with on the Mittenwald Railway, it was necessary to depart somewhat from American practice. Special insulators devised by the A.E.G. Company have also been used for anchoring the contact line.

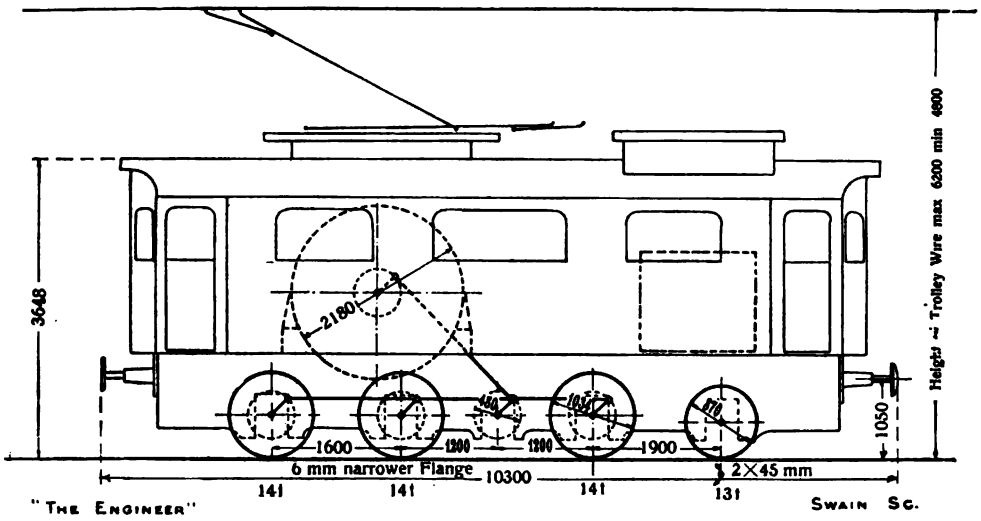


Fig. 174.—Diagram of Locomotive for the Mittenwald Railway.

The illustrations of the Scharnitz station and the Wilten shunting station in Figs. 170 and 171 give a good idea of the overhead equipment as used on the Mittenwald Railway. In this instance the A.E.G. Company has not provided any tightening gear for the overhead lines. The reason for this appears to be that the many sharp curves entail considerable friction, which makes it impossible for any ordinary tightening device to work satisfactorily. Moreover, owing to the flexibility of the masts used on this line, gear of this description was considered unnecessary. Fig. 172 shows the arrangement of the contact wire in a tunnel.

Let us now pass on to the electric locomotives. At present nine 800 h.p. single-phase locomotives are in use on the Innsbruck Landesgrenze and Bayern-Garnisch-Partenkirchen lines, representing a distance of 75 km. Each locomotive can draw a train weighing 124 tons on a gradient of 3·64 per cent. at a speed of about 30 km. per hour, this corresponding to a tractive effort of approximately 7,500 kilos. A train standing in the Hochzirl station is shown in Fig. 173. It is worthy of mention that one of these locomotives was put into service for some months on the Dessau-Bitterfeld Railway, in Germany, for trial purposes, during which time it hauled goods trains weighing 1,100 tons at the regular schedule speeds.

The diagram, Fig. 174, shows the axle arrangement, position of motor and main transformer very clearly. The hourly rating of this goods locomotive is 800 h.p. at a speed of 30 km. per hour, the maximum speed being 40 km. per hour. When the locomotive is ready for service with the sand box filled, etc., the total weight is 53 tons, this being 3 tons under the weight specified. The reduction was effected solely by cutting down the weight of the electrical equipment. Current is collected from the overhead wire by means of bow collectors, and is led through a bare conductor on the roof to a lightning arrester and choking coil and then to the primary of the main transformer. The high-tension oil switch, which can be closed by hand from the driving cab, breaks the circuit at four points, and a resistance is provided in the usual manner. Press buttons are fitted for the purpose of opening this switch.

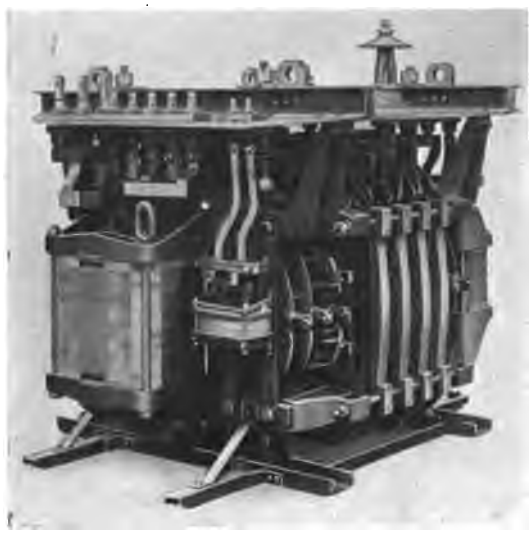


FIG. 175.—Locomotive Transformer.

Between the lightning arrester choking coil and the oil switch an earthing switch is connected which automatically closes when the protecting cover of the switch is removed. A main transformer, as used on these locomotives, is shown in Fig. 175. Fig. 176 shows one of the 800 h.p. A.E.G. single-phase motors erected on the test bed. It is a 12 pole machine, and is con-

FIG. 176.—800 h.p. Single-Phase Motor on Test Bed.

structed in accordance with the designs of Winter-Eichberg. Two sets of brushes are fitted to these motors, the brushes of one set being short-circuited. The exciting current is fed into the rotor through the second set of brushes, this current being derived from a special exciting transformer. The slots of the rotor are partially closed, and are skewed at an angle with respect to the rotor axis. Fig. 177 shows one

of the rotors. Speed control is effected by changing the pressure at the terminals of the motor, this being done by means of contactors which are connected to the tappings of the main transformer.

The controlling current for the contactors is taken from the power transformer of 300 volts. Each of the two controllers has two drums. One operates the contactors for the power transformer, and thus regulates the output, whilst the second operates the exciter contactors, thereby controlling the excitation. The direction of running is also determined by the first position of the exciter drum. The drums are independent of one another. Owing to this arrangement the field can be adjusted for any speed with the lowest possible kilovolt-ampere input at the terminals of the motor. All the contactors are interlocked with one another. If one of the contactors fails to operate, the others cannot be closed. It was specified that it should be possible to operate two locomotives on the multiple unit system, so that in this case trains weighing 250 tons can be hauled. The contactors for the auxiliaries, such as motor compressor, lighting, and heating, are mounted on a common switchboard, and the controlling leads are energised on closing hand-operated switches. The pressure used for lighting is only 19 volts.

FIG. 177.—Rotor of 800 h.p. Motor.

The motor compressor, which supplies the compressed air for the brakes, current collectors, sanding gear, and whistle, is automatically switched in as soon as the air pressure in the tank has fallen below a given value, and when the proper pressure is restored the current is automatically interrupted. The heaters used for heating the locomotives consume 1 kw. For heating the trains couplings are fitted at each end of the locomotive and coaches, and by means of coupling cables a circuit is established throughout the train. Lastly, it is worthy of mention that a three-way cock is interposed in the compressed air pipes and connected with levers in such a manner that the air leaves the cylinder of the current collector directly anyone mounts the roof of the locomotive. The collector is therefore lowered, and all the current carrying parts on the top of the engine can be handled with safety. The whole of the electrical work was carried out by the A.E.G. Company.

CHAPTER V

THE ST. PÖLTEN-MARIAZELL RAILWAY

ONE of the most interesting lines electrified on the single-phase system by Siemens-Schuckert is the Alpine Railway, which runs from St. Pölten, in lower Austria, to Mariazell in Styria, and which is connected with the Austrian State Railway at St. Pölten. When the line was first put into operation it was worked by steam, but it soon became evident that something would have to be done to increase its capacity to enable it to cope with the very heavy goods and passenger traffic.

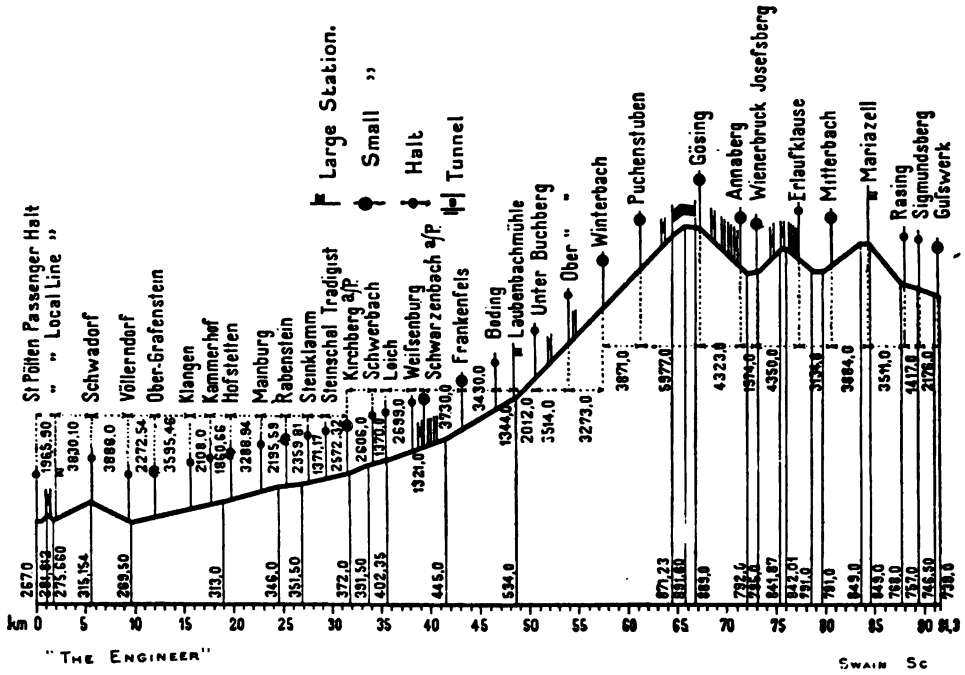


FIG. 178.—Profile of the St. Pölten-Mariazell Railway.

Moreover the smoke in the tunnels proved very objectionable. There are sixteen stations and seventeen passenger halts, the principal stations being at St. Pölten, Laubenbachmühle, and Mariazell. The heights of the various stations and passenger halts above sea-level and their distances from the station at St. Pölten are shown on the diagram, Fig. 178. The smallest radius of curvature is 260 ft., and the steepest gradient 2·5 per cent. Since the greater part of the railway passes through mountainous country it became necessary to build many tunnels and viaducts. Altogether there are 136 large and nineteen small arched bridges with a total length of 1,065 m. These are built partly in stone, and partly in steel. There are also seventeen tunnels with a total length of 4,000 m. The gauge of the line is ·76 m. In the Gösing Tunnel, which is 892·5 m. long, the highest point of the railway is reached, viz., 892·5 m. above the sea-level.

During the year 1907, when the line was worked by steam, 532,000 passengers

and 127,000 tons of goods were carried. In the following year—the second year of working—these figures had still further increased, and it then became evident that steam locomotives were unsuitable for dealing with the heavy traffic. The question of running night trains was considered, but this did not provide a solution to the problem, since most of the passengers desire to travel in daylight, owing to the beauty of the surrounding country. Nor was it considered expedient to run a night service for the goods, since this would have necessitated the employment of an additional staff, with a consequent increase in the working expenses.

The lengthening of the trains and the provision of a second locomotive also proved impracticable, owing to the many sharp curves in the cuttings and tunnels, and the smoke nuisance arising from the employment of two locomotives. It was decided, therefore, that the only satisfactory solution to the problem was to electrify

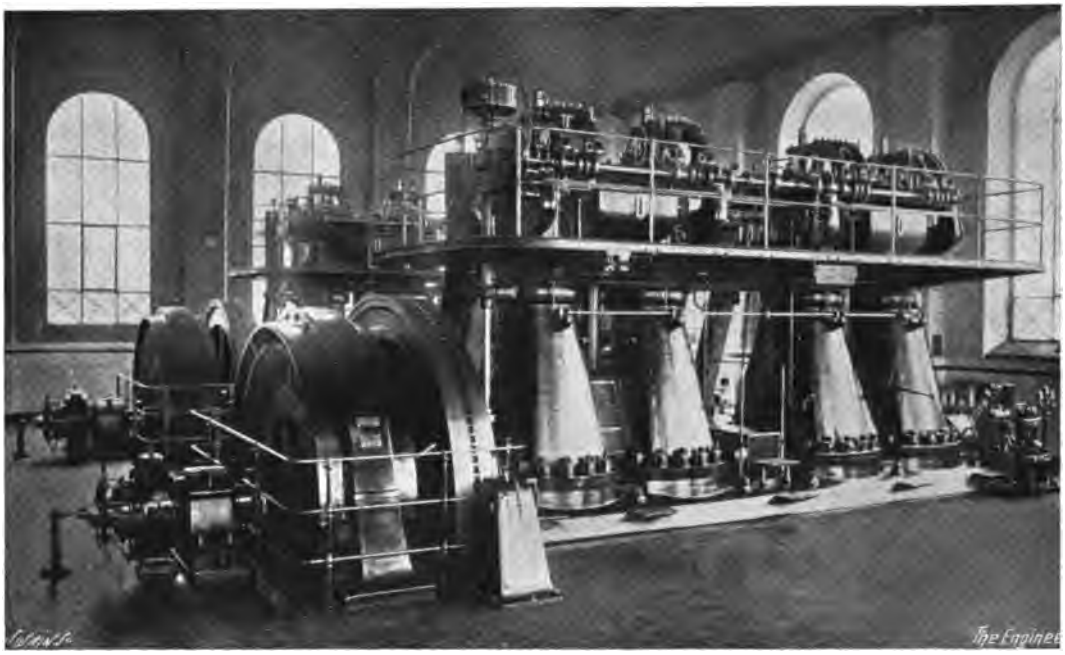


FIG. 179.—Interior of Power Station at St. Pölten.

the railway, and this appeared particularly desirable on account of the abundance of water power in the vicinity.

For the purpose of providing power for working the railway, hydro-electric stations were erected at Wienerbruck and at Trübenbach, and they utilise the falls of the Lassingbach and Erlauf Rivers. In order to assist these stations at times when water is scarce an oil engine station has also been built at St. Pölten. An illustration of this station is shown in Fig. 179. In addition to supplying energy for working the railway, the stations also provide current for power and lighting in connection with various industrial establishments in St. Pölten and other places in the vicinity of the railway.

A great deal of current is consumed in the town of St. Pölten, which also possesses a municipal electric supply station of its own, and two other large stations in Wilhelmsburg Ratzersdorf are connected with this. As can be seen from Fig. 180, six power houses are now working on a common distribution system, and they are equipped

partly with water turbines, partly with steam engines, and partly with gas and Diesel engines.

It was considered desirable that every alternator should be capable of generating

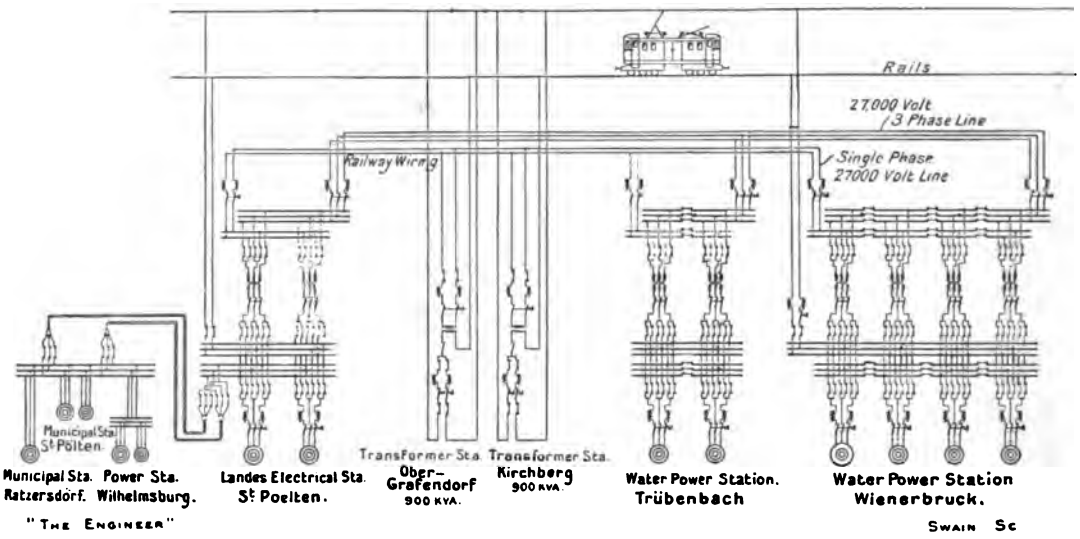


FIG. 180.—Scheme of Connections for Power Houses.

three-phase current so that each set could be used for the railway as well as the three-phase power supply. Accordingly the alternators have been constructed as three-phase machines, and the switching arrangements enable either one or three phases to be used. The power station at Wienerbruck is on the first stage of the fall, and is situated in a deep gorge of the Erlauf River. In order to equalise the irregularities of the water supply, a dam has been erected to enable the water of the Lassingbach River to be stored, and this dam, which is shown in Fig. 181, is near the Wienerbruck station. A similar dam has also been built for dealing with the water of the Erlauf River, and this is situated near the Erlaufklause station.

FIG. 181.—The Dam at Wienerbruck.

There were originally three water turbines in the Wienerbruck station, each capable of developing 1,000 h.p. when running at a speed of 375 revolutions per minute. Later a fourth set was erected. The useful fall amounts to 170 m. The alternators coupled to the three first mentioned turbines are designed for a three-phase output

of 1,340 kilovolt-amperes and a single-phase load of 900 kilovolt-amperes. The voltage is 6,500, and the periodicity 25 cycles per second. The generator coupled to the large turbine is designed for a three-phase load of 2,600 kilovolt-amperes, or a single-phase load of 1,800 kilovolt-amperes, the voltage and periodicity being the same as for the other machines. It will be understood that the large three-phase capacities of the machines are due to the fact that it was desirable to utilise the full power of the turbines when working on single-phase load. To maintain the voltage constant automatic regulators are used. These are constructed in accordance with the Dick system. To prevent these regulators increasing the strength of the field current when short circuits occur relays are connected in the supply circuit, and they

FIG. 182.—Overhead Construction with Masts inside Curve.

FIG. 183.—Overhead Construction with Masts outside Curve.

disconnect the regulators when abnormal currents, set up by short circuits, occur. The Wienerbruck power station also contains transformers which raise the pressure from 6,500 to 27,000 volts for the long distance transmission line. These transformers can be used for the three-phase as well as for single-phase supplies.

The power station utilising the second fall of the Erlauf River is at Trübenbach. For equalising the flow of water a dam has been erected below the power station of Wienerbruck, and this also deals with the water of the Otscherbach River. The useful fall at this point amounts to 120 m. The Trübenbach station is designed as a simple three-phase station. It contains two three-phase generators of the Siemens-Schuckert type, each of which has a capacity of 1,200 kilovolt-amperes. The terminal voltage is 6,500, but this is increased by means of transformers to 27,000 volts for the

high-tension transmission line of the railway. The power station on the third fall of the Erlauf River is to be at Urmannsau, and its electrical equipment will correspond to that of the Trübenbach station.

The Landes station in St. Pölten, which, as already explained, serves as an auxiliary for the three water power stations, contains two Diesel engines each having a capacity of 800 h.p. They are coupled to three-phase generators of the Siemens-Schuckert type. Each generator is designed to give 700 kilovolt-amperes three-phase current, or 420 kilovolt-amperes single-phase current. The pressure is 5,000 volts, and the periodicity 25 cycles per second. In this station the 27,000 volt current derived from Wienerbruck and Trübenbach is connected to the primaries of the distribution transformers, which feed the 5,000-volt circuits of the city system.

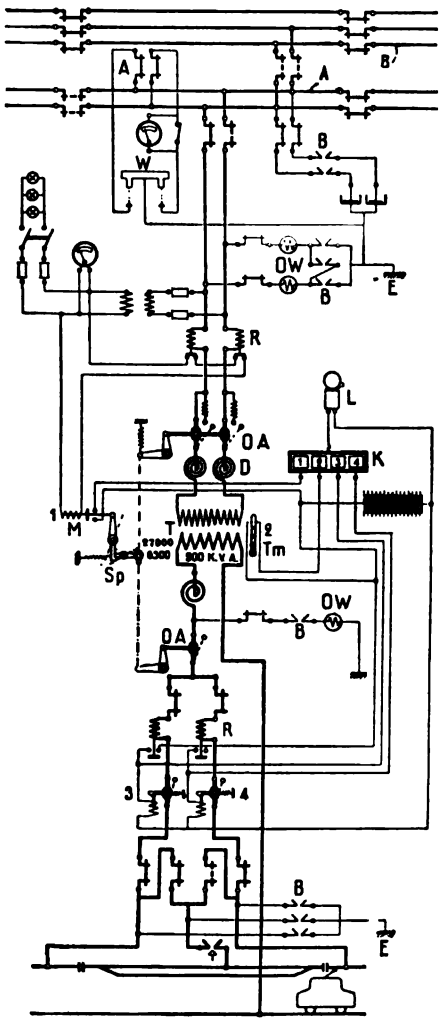


FIG. 184.—Sub-Station Connections.

Referring to the diagram, Fig. 180, it will be seen that the current at 6,500 volts for the railway is supplied direct from the power station at Wienerbruck. At the opposite end of the line, however, the sections are fed through transformer stations at Kirchberg and Ober-Grafendorf, which are connected with the Wienerbruck power station by the 27,000-volt transmission line. The single-phase transmission wire from Wienerbruck as far as the sub-station at Kirchberg consists of two hard drawn copper wires of 50 sq. mm. section, and from Kirchberg to the sub-station of Ober-Grafendorf of two wires of 35 sq. mm. section. A third transmission line consisting of two copper wires of 35 sq. mm. section also runs to the Landes power station at St. Pölten, and in this way it becomes possible to supply the railway with current from this station. There is also a three-phase 27,000-volt transmission line running from the power station at Wienerbruck to St. Pölten, and this consists of three copper wires each having a section of 35 sq. mm. This line carries the current, which is used for power purposes, in various industrial works along the railway. The power station at Trübenbach is connected up to this transmission line, and the line is also connected with the two transformer stations, as shown in the diagram, Fig. 180

By means of suitable switching arrangements, therefore, it is possible to maintain the supply under practically all adverse conditions. Most of the high-tension transmission wires are carried on insulators mounted on the masts which support the contact wire for the railway, as shown in Figs. 182 and 183. All the masts are earthed by connecting them to the rails, and also to a buried wire running along the line. The earth connection is made by a galvanised iron wire. This wire is also connected to earth

plates. In order to avoid accidents due to the breakage of the 27,000-volt wires, metallic loops which are earthed are fixed to the masts as shown in Figs. 182 and 183.

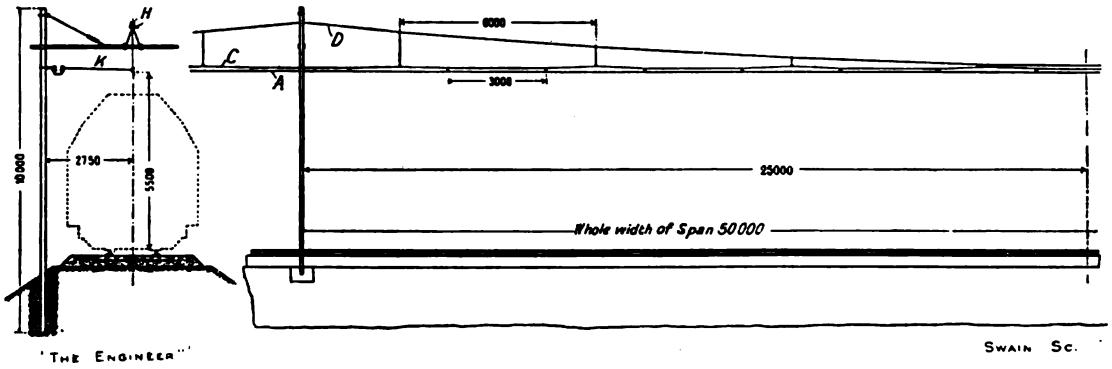


Fig. 185.—Details of Overhead Construction.

Under ordinary conditions these loops are well away from the high-tension wires, but in the event of the latter breaking, the falling wire makes contact with the loops, and so causes a short circuit. It has only been necessary to use guard nets in a few places. For protecting the high-tension wires against the effects of atmospheric disturbances, lightning arresters are fitted in the power stations and sub-stations. The transformer sub-stations Kirchberg and Ober-Grafendorf are small masonry buildings, and are in the immediate neighbourhood of the railway stations of the same names. A diagram of connections of one of these sub-stations is given in Fig. 184. From this it will be seen that the transformers can either be fed from the single-phase wires A or from one phase of the three-phase lines B. The transformers, which are indicated at T, have a ratio of 1 to 4·15, and transform the 27,000-volt current to 6,500 volts for use on the railway. Two transformers each rated at 900 kilovolt-amperes are erected in each of the sub-stations. The transformers are of the oil type with natural cooling.

Fig. 186.—Automatic Line-Tightening Gear.

For opening the primary, an oil switch is used as indicated at OA, and this is automatically opened by a release gear S*p* in the event of an abnormal rush of current occurring. Time relays R are also used in conjunction with the trip gear. When the trip gear operates, a bell as shown at L rings in the station inspector's office. Moreover an indicator K shows at a glance which of the switches requires closing.

Another interesting feature is the provision of an audible signal, which indicates the occurrence of an abnormal rise of temperature in any of the transformers. When switching on the primaries of the transformers, resistances are connected in circuit to limit the first rush of current. The undesirable effects due to induction when switching off the transformers are also guarded against in a like manner. It only remains to direct attention to one or two other details, which are lettered on the diagram. M is the electro-magnet for actuating the trip gear, D the choking coils, B the lightning arresters, OW a water jet; T*m* is a thermometer used in connection

FIG. 187.—Overhead Construction on Curve with Brackets and Pull-offs.

FIG. 188.—Line-Tightening Gear at Mouth of Tunnel.

with the temperature indicator, and K the indicator for showing which switch requires attention after the trip gear has operated.

Both transformer sub-stations mentioned are identical, with the exception that at that at Ober-Grafendorf there are no water jet lightning arresters, since those provided at the auxiliary station at St. Pölten serve for protecting this sub-station against the effects of lightning. Owing to the increase of traffic on the railway it became necessary to erect a third sub-station. This has been put down at the railway station at Laubenbachmühle. As shown in Fig. 184, two feeders, from the secondary of the transformer, conduct the current to two parts on the railway, and one of these feeders supplies current to the section on the right of the sub-station, and the other to that on the left. Section insulators are interposed between the sections, but under normal conditions these are short circuited. When all the separating switches are closed the contact wiring is continuous. By opening the section

switches, however, the various parts of the line can be made dead in the usual manner.

The overhead wiring, which is worked at a pressure of 6,500 volts, is suspended by a catenary cable, and auxiliary wire, as shown in Fig. 185. The contact wire A is of hard drawn copper, and has a section of 80 sq. mm., and is suspended from the auxiliary wires at distances of 3 m. by means of droppers. The droppers between the catenary cable and the auxiliary wire are placed 6 m. apart. The auxiliary wire C is a steel wire of 6 mm. diameter, whilst the catenary cable D is a steel cable made up of seven strands, and has a total section of 35 sq. mm. The whole suspension system is carried on insulators H.

Owing to the large amount of water in the tunnels, it was found necessary to use catenary and auxiliary wires made of bronze. To avoid side oscillation of the contact wires, struts K are used. These are insulated from the supporting masts by double insulators as indicated in the diagram. On curves these struts act as pull-offs, and compel the wire to conform with the curve of the rails. In stations where there are several lines running

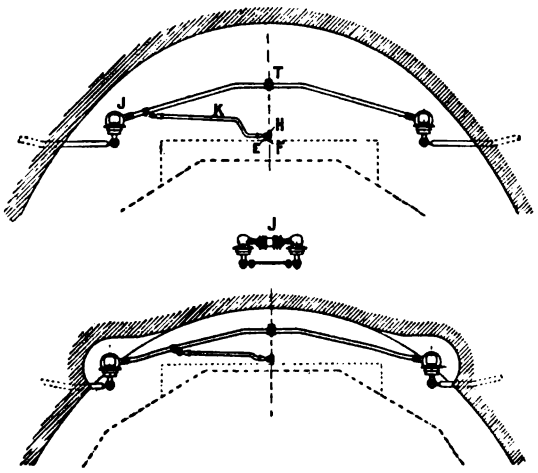


FIG. 189.—Methods of Supporting Wire in Tunnels.

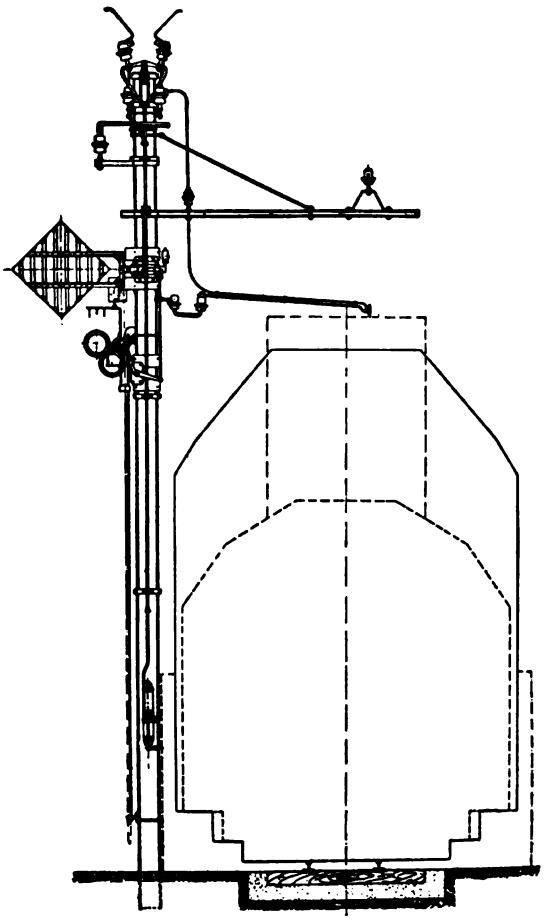


FIG. 190.—Section Switch on Mast.

side by side cross brackets are employed, and these are supported by the masts on both sides of the permanent way. The height of the contact wire above the rails on the open sections of the line is 5·5 m. Many of the masts used for supporting the wires are simply girders of I section, whilst in other instances lattice masts are employed. The span from mast to mast amounts to 50 m. In view of the fact that the construction of the overhead equipment is more or less evident from the illustrations 182, 183, 186, 187 and 188, it is unnecessary to enter into all the details, but there are, nevertheless, one or two special points to which attention should be called. For example, the erection of the overhead wiring in the tunnels presented

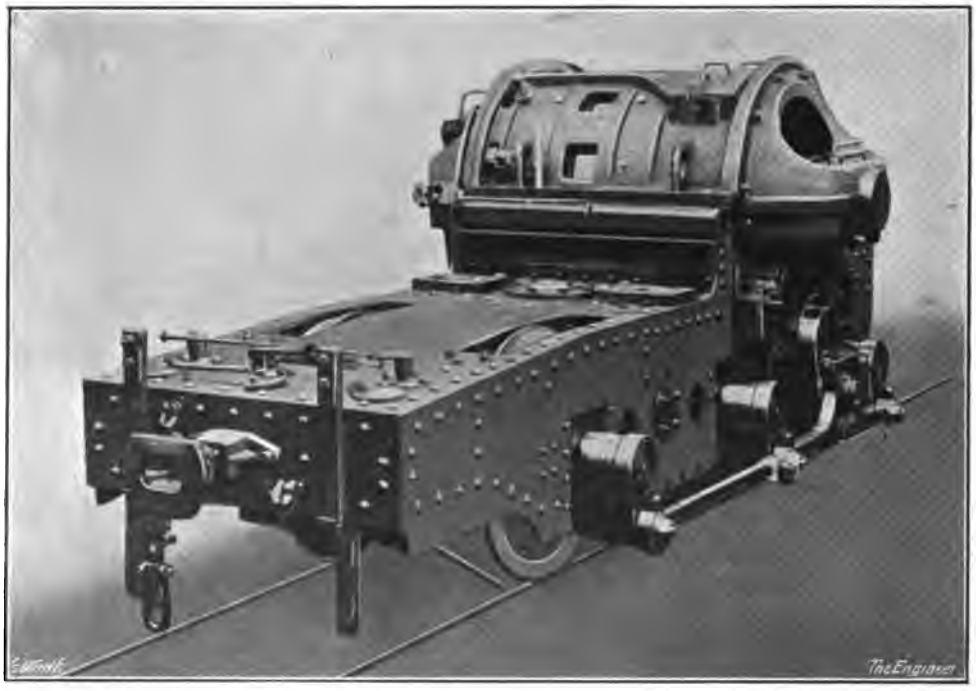


FIG. 191.—Locomotive Motor Bogie.

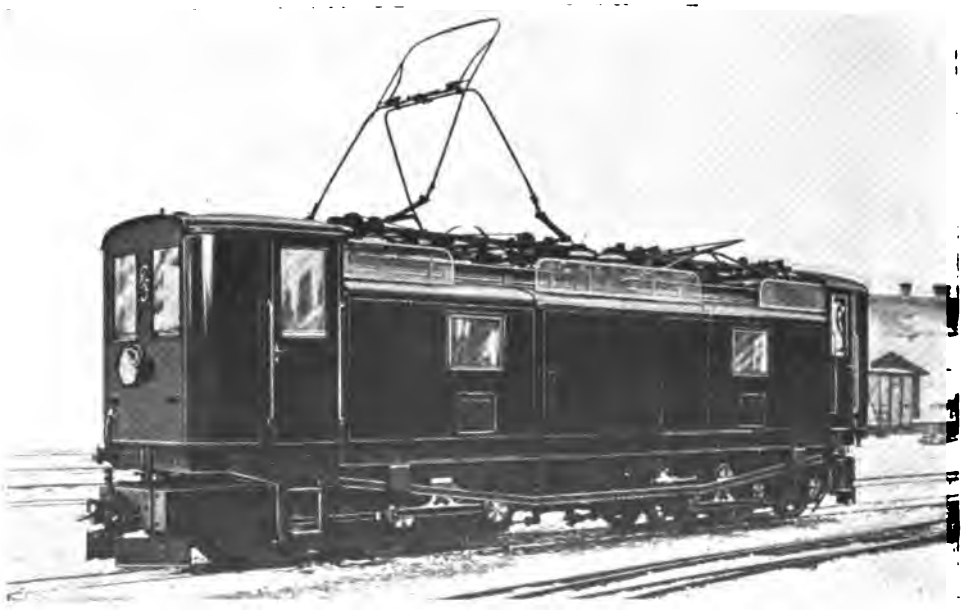


FIG. 192.—Single-Phase Locomotive.

difficulties, and some special arrangements had to be adopted. The troubles were brought about owing to the small amount of space available for the catenary suspension system.

The method of overcoming the difficulty is shown in Fig. 189. The clearance space in the lower drawing is considerably below that in the upper illustration. The wire is only 3·7 m.—12 ft.—above the rails. The supports are placed 18 m. apart. It will be seen that special insulators J are fixed at each side of the tunnels, and that these support cross brackets, and the latter are constructed of steel tubing. The contact wire is shown at F, the auxiliary wire at H, the cross bracket at T, and the strut for preventing side oscillation at K. E is a common support for the wires F and H.

FIG. 193.—300 h.p. Motor.

The insulators are not in line with the centre of the permanent way, and although this is of little importance when all the trains are worked with electricity, it nevertheless proved a boon in the present instance, since the overhead equipment in the tunnels was erected about twelve months before electric working was started. The engineers had reason to believe

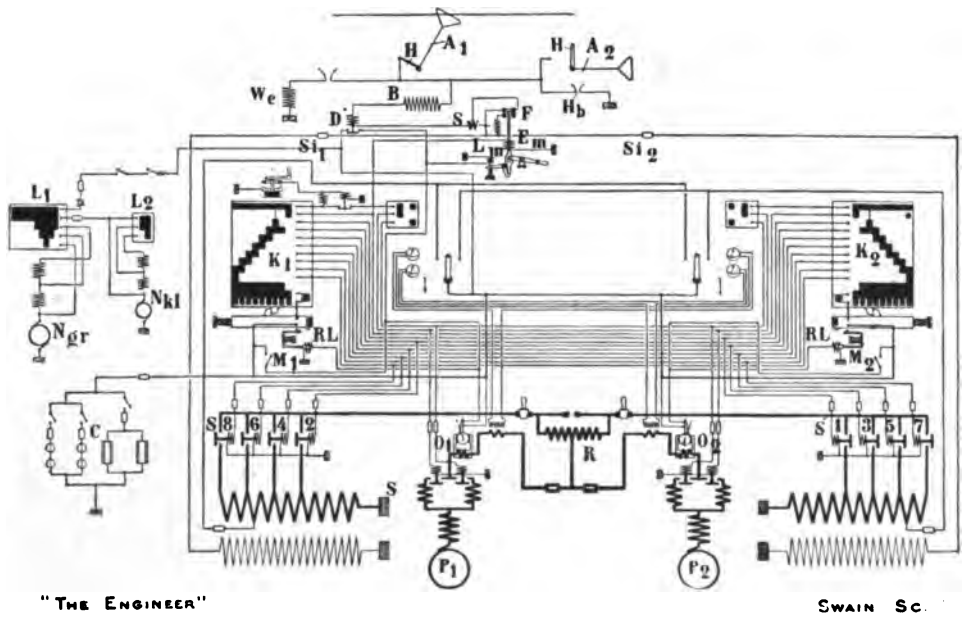


FIG. 194.—Locomotive Connections.

that had the insulators been in direct line with the smoke coming from the funnels of the steam locomotives a great deal of damage wou'd have been done to them. But as it was the insulation proved perfect when the high-tension current was switched on. In front and behind the stations, and also in front and behind tunnels, which are over 200 m. long, section insulators are interposed in the wiring, as shown in

FIG. 195.—The Wienerbruck Dam on the Way to Annaberg.

FIG. 196.—The Line Crossing a Valley.

Fig. 188, and these render it possible to make the station and tunnel sections dead. The sections are cut out by means of horn switches, which are erected on the masts. These switches are actuated by rods. For the purpose of dividing the sections the ends of the wires are fastened to two brackets, which are placed 10 m. apart.

The wires are led near one another, and with a slight gradient, so that the current collectors can glide from one wire to another without impact. In the stations with loading sidings, section dividers of a simple type are used. They are directly connected in the wiring, and are fitted with horn switches and a shutter signal, so that it is possible to see at a glance whether a section switch is opened or closed. A section divider of this type is shown in Fig. 190.

When the electrical working was first commenced there were 14 narrow-gauge—·76 m.—electric locomotives, each of which weighs 47 tons. They are bogie locomotives, and are specially designed for negotiating sharp curves. Each bogie has three coupled axles. The engine will draw a 100-ton train at a speed of twenty-five miles per hour on a 2·5 per cent. gradient. The draw bar pull on this gradient is about 5 tons. The maximum tractive effort at the rim of the drivers is 10 tons. One of the bogies is shown in Fig. 191, and a complete view of one of the locomotives is given in Fig. 192. The motor, it will be observed, is placed at one end of the bogie, and it transmits its power through gearing on to an intermediate shaft which is coupled by means of a crank to the side drivers. Each locomotive is propelled by two motors, one on each bogie, and the capacity of each motor is 300 h.p. The speed is 700 revolutions per minute, the voltage 220, and the periodicity 25 cycles per second.

FIG. 197.—The Saugraben Viaduct.

The motors are of the natural air-cooled type, and there are no resistance connections between the armature windings and commutator segments. It will be noted that the motors are fairly high speed machines. Their weight, exclusive of the gear and gear casing, is 4,700 kilos. An illustration of one of the motors is given in Fig. 193, and a diagram of connections for one of the locomotives in Fig. 194.

This is fairly simple to follow, but it may be well to point out the main parts. A_1 and A_2 are the current collectors, B the choking coil, D a high-tension relay, F the high-tension switch, E*m* the overload coil for the high-tension switch, M the release magnet, S*i*$_1$ and S*i*$_2$ fuses, H high-tension switches coupled with the current collectors, H*b* the lightning arrester, K_1 and K_2 controllers, L_1 and L_2 vacuum brake motor switches, M_1 and M_2 emergency press buttons for operating the main high-tension

switch, N*gr* and N*kl* vacuum pump motors, O_1 and O_2 heavy current relays for the main motor circuit, P_1 and P_2 main motors, R preventive coil for avoiding breaking the main motor circuit when the connections are changed, S_1 to S_8 contactors, W*e* resistance in series with lightning arrester, and C the lamps and heating apparatus.

The illustration, Fig. 195, shows the dam at Wiesenbruck on the way to Annaberg, and Fig. 196 a viaduct and inclination of the line in a valley. Fig. 197 shows the Saugraben viaduct.

CHAPTER VI

THE MARTIGNY-ORSIÈRES RAILWAY

THIS is a Swiss railway extending from Martigny to Orsières. There are intermediate stations at Martigny-Bourg, Martigny-Combe, Bovernier, and Sembrancher. The railway is about 19·3 km. long, and constitutes an exceedingly interesting example of single-phase working.

The passenger trains are usually made up of one motor coach and one or two trailer coaches, and run at a speed of 30 to 45 km. per hour, according to gradient. Motor coaches are also employed for the goods traffic, and are capable of hauling a total weight of 130 tons at a speed of from 15 to 25 km. per hour. It was specified, however, that when carrying a weight of 20 tons the goods motor coaches were to be capable of attaining the same speed as the passenger motor coaches, so that they could be used for carrying passengers if desired. It was at first proposed to use continuous current at a pressure of 2,400 volts, measured between the rails and the overhead wire. Upon further investigation, however, it was found that a higher pressure was desirable, and eventually an 8,000-volt single-phase system was decided upon. In the first instance it was intended to adopt a periodicity of 25 cycles per second, but in consequence of the recommendations of the Schweiz Studienkommission for the Working of Electric Railways, which were issued before the work was begun, a periodicity of 15 cycles per second was adopted. The whole of the electrical work for this railway was carried out by Brown, Boveri & Co.

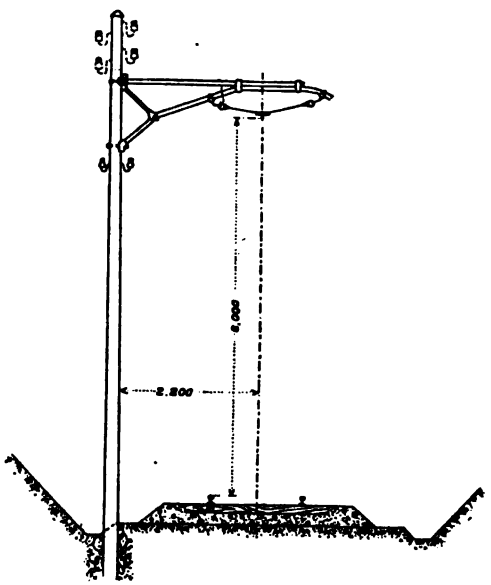


FIG. 198.—Bracket Pole.

Originally it was intended to take power from a large hydro-electric station in the neighbourhood of Orsières, which supplies current to electro-chemical works, but this plan was abandoned. At present current is derived from a station belonging to the Société d'Electrochimie, at Martigny-Croix. At the outset one of the 10,000-volt 25-cycle generators in this station was used for supplying the current to the railway at 8,000 volts and 15 cycles. In order to obtain the lower periodicity and voltage, the speed of the machine was reduced by cutting out some of the nozzles of the turbine. This produced the correct periodicity, but the pressure corresponding to the lower speed of the generator was only 6,000 volts, and, consequently, the use of a 400-kw. auto-transformer became necessary to raise the voltage to 8,000, as needed for the railway. This arrangement, however, did not give altogether satisfactory results, and a new generating set giving the correct periodicity and voltage has now been erected. The set has a capacity of 600 kw., and was constructed by

Brown, Boveri & Co. The governing gear enables the pressure to be maintained within 5 per cent. of the normal working pressure.

The overhead equipment is simple. The conductor consists of a round copper wire having a section of 50 sq. mm. For the single suspension system on the sections of the railway in the open country wooden poles are used for supporting the overhead wires. Brackets constructed of $1\frac{3}{4}$ in. piping are attached to these poles in the manner indicated in Fig. 198. On straight lengths of track these poles are spaced 35 m. apart.

From the illustration, Fig. 198, it will be seen that the height of the overhead wire above the rail is 6 m. In the streets, however, the height of the wire is increased to 7 m., whereas in tunnels (see Figs. 199 and 200) it is reduced to 4·9 m. In this system of suspension three separate insulators are interposed between the conductor and he brackets. The cross or span wire, which supports the conductor, is insu'ated from the brackets by means of grooved porcelain insulators, whilst the insulators

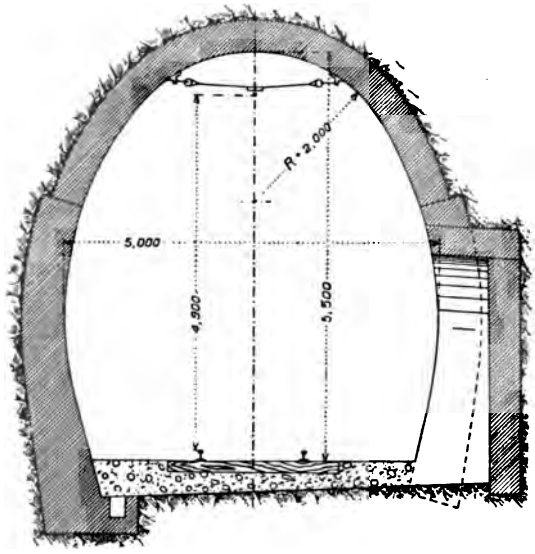


FIG. 199.—Method of Supporting Wire in Tunnel.

FIG. 200.—Entrance to Tunnel.

between the cross-wire and conductor are of hard rubber. In the neighbourhood of the stations a simple catenary system of suspension is adopted, as shown in Figs. 201 to 203, and where several tracks come together the catenary wire is supported on cross-supports constructed of stiffened piping. These cross-supports carry double bell insulators, which support a steel-stranded catenary cable having a section of 35 mm. The conductor is carried by vertical droppers, which are spaced 3 m. apart. Where this catenary system of suspension is adopted the poles are spaced 50 m. apart, except at places where curves and sidings demand a smaller distance. The sections of the overhead wire passing through the stations can be cut off from the main track by means of an oil switch, and wooden section dividers are interposed in the overhead conductors at the ends of the stations. Under normal conditions, however, these section insulators are short-circuited. The wires which connect the station overhead conductors with the main track conductor, and which are branched off at each side of the section insulators just referred to, are carried on the masts which support the main conductors. The two ends of these branch wires terminate in an oil switch, so

that when the latter is opened the trolley wire in the station is cut off from the wire on the main track. The feeder wires are also connected to a similar switch.

These switches, together with the lighting transformer, are enclosed in a switch-

FIG. 201.—Station and Switch-Box at Martigny-Bourg.

box, as shown in Figs. 201 and 204. The switch-boxes are placed opposite the station buildings, as shown in Fig. 201, so that they are in full view of the station officials. Red and green signal lights are fixed in two apertures in the front of the box, so that

FIG. 202.—Orsières Station.

at night the station officials can see whether the switches are opened or closed, and so determine what tracks are alive or dead. In the event of a section being switched out on account of trouble, it is the duty of the station officials to give the signal for

the train about to enter the dead section to be brought to a standstill. When a section is switched off it is earthed so that the wire can be handled with perfect safety. The loading and siding tracks of the larger stations can also be separated from

FIG. 203.—Passenger and Goods Train.

the main tracks. Fig. 205 shows a different section switching arrangement as used at Orsières. The rails are bonded together at every 100 m., in accordance with the special method of bonding adopted by Brown, Boveri & Co., the bonds con-

FIG. 204.—Switch-Box at Martigny-Bourg.

FIG. 205.—Section Switch at Orsières.

sisting of 8 mm. copper wires. The maximum drop, including that in the return feeders connected to the rails, is about 12 per cent. For lighting the stations a

FIG. 206.—Drance Bridge.

pressure of 100 volts is employed, and current is taken from the secondary side of the transformers situated in the switch-boxes. The capacity of these transformers ranges from 1 to 2 kilovolt-amperes. At stopping-places where there are no switch-boxes the lighting transformers are fastened to the masts which support the overhead conductor. The cables for lighting the stations are carried underground to the distribution board in the station buildings. All the stations, as well as the chief depot, in Orsières are connected together with a telephone system, the wires for which are carried on the masts which support the working conductors of the railway. A good idea of the simple character of the overhead construction in the open country can be gained from Fig. 206, showing a bridge at Drance. Fig. 207 shows the overhead lines at a siding.

FIG. 207.—Overhead Equipment.

Originally, the rolling stock consisted of two passenger motor coaches, two goods motor wagons, two passenger trailer coaches and four ballast wagons. The motor bogies for the passenger and goods wagons are identical. The wheel-base measures 2,500 mm., whilst the diameter of the wheels is 1,150 mm. An illustration of one of the motor bogies is given

in Fig. 208. Each bogie truck carries a sheet iron box lined with asbestos, in which the low voltage cut-outs of the motors are placed. The bodies of the coaches are constructed of oak and pitch pine, and the frames of iron. Westinghouse automatic and non-automatic brakes are employed, and also a hand brake. Owing to the special system of control, which will be described presently, the spaces between the motor bogies of the motor coaches has been kept perfectly free from brake levers, so as to allow ample space for the electrical control equipment. With this object two separate brake lever systems are placed at each end of each motor coach, and are actuated from a 10-in. brake cylinder, and each supplies air to the shoes of the bogie truck to which it belongs. These cylinders are put into operation by wires, so that the brakes can be applied to all the shoes of a motor coach from both platforms. The main air containers for Westinghouse brakes are placed on the roofs of the motor coaches, as shown in Fig. 209, and are constructed in the form of pipes

FIG. 208.—Motor Bogie.

which also serve to support the current collectors. Compressed air is also used for the sanding device and the whistles.

The passenger motor coaches are provided with a driver's compartment at each end, and next to each of these there is an entrance for the passengers. There are two third-class compartments, one smoking and the other non-smoking. In addition there is a second-class compartment capable of seating eight passengers, and a baggage compartment with the usual postal arrangements. The four-axle passenger trailer coaches are very similar to the motor coaches, except, of course, that there are no driver's compartments. Two-axle trailer coaches are also used on this railway. As already stated, it is possible to use the goods motor coaches for passenger service, and, as will be gathered from Fig. 210, the goods coaches are provided with passenger compartments. In addition to the space for goods, and the accommodation for the postal service, there are two third-class compartments with a total of sixteen seats. As regards the other equipment, such as brakes, bogie trucks, etc., this corresponds to that of the passenger motor coaches. The internal equipment for all coaches conforms with that of the Swiss Federation Railways. All the rolling stock was built by the Schweiz Waggenfabrik Schlieren A.G., and the electrical equipment by Brown, Boveri & Co.

Perhaps the most interesting feature of this railway is the type of motor used on the motor coaches. It is the Déri repulsion motor, developed by Brown, Boveri & Co. Briefly stated, the stator winding is entirely independent of the armature, and is supplied with current at a constant pressure, and speed variation is effected by shifting the brushes. The armature is provided with two sets of brushes, one of which is fixed and the other movable. The movable brushes are connected to the fixed brushes by flexible cables. To bring the armature to rest the movable brushes are shifted so as to be in line with the axis of the stator, but by turning this set of brushes out of this position the armature is made to revolve, and the direction of rotation is opposite to the direction in which the brushes are turned. The normal working range of the motor lies between four-sixths to five-sixths of a pole pitch, or between 120 to 150 degrees. When a movable brush shifts away from a fixed brush, electrical conductivity is preserved between the two. When the brushes are brought together there is no difference of potential between them, and under these conditions

FIG. 209.—Passenger Motor Coach.

no current flows in the armature. Thus, the only current taken is the magnetising current, so that the conditions that exist correspond to those which prevail when the primary of a transformer is connected across the mains and when there is no load on the secondary circuit.

But as soon as the movable brushes are shifted away from the fixed brushes a difference of potential between the fixed and moving brushes is produced, and since they are connected together a current flows in the armature turns lying between the brushes that are connected. The Déri motor has series characteristics, that is to say, the number of revolutions drops with an increase in load. With different brush positions different characteristics are obtained entirely analogous to a series-wound motor working with various voltages, and the number of revolutions increases with the brush displacement. If we consider the torque with respect to the brush position at the same number of revolutions, then the torque increases with the brush displacement, so that the torque is greater the lower the speed, and is greatest at starting. The starting torque can be made much greater than the normal running torque.

Generally speaking, ordinary Déri motors develop a starting torque about two and a half times greater than the normal running torque. The efficiency for different loads is about the same as that of a series motor, and within the usual ranges of working load the power factor compares favourably with that of a series machine. From the foregoing it will be gathered that the whole of the speed variation is carried out by displacing the brushes. The Déri motors employed on the Martigny-Orsières Railway are four-pole machines, and are designed for a pressure of 500 volts and a periodicity of 15 cycles per second. The hourly rating is 90 h.p., the weight inclusive of gearing being 2,500 kilos. Each passenger motor coach is fitted with four motors, and the same applies to the goods motor coaches. In order to fulfil the different conditions called for as regards speed, however, the gear ratio in the case of the goods trains is 1 to 3·28, and in the case of the passenger trains 1 to 2·53.

The illustration, Fig. 211, shows the arrangement of one of the Déri motors and gearing, and Fig. 212 the electrical connections for one of the motor coaches.

FIG. 210.—Goods and Passenger Motor Coach.

The current is taken from overhead conductors by two pneumatically operated pentagonal current collectors. The current then passes into the primaries of the two transformers marked T, and then to earth by way of the rails. As usual, a lightning arrester and choking coil are connected to the main high-tension cable leading to the primaries of the transformers. A single-pole maximum cut-out is also connected in series with the high-tension primary circuit. It will also be noticed that there is a current transformer *St* connected to the ampere meters, and trip gear for opening the main switch. We will neglect these minor details for the present, however, and pass on to the system of control.

Each transformer has a capacity of 130 kilovolt-amperes and a ratio of 16 to 1, since the primary pressure is 8,000 volts and the secondary pressure 500 volts. Inspection of the diagram reveals the fact that the four stator windings of the motors are connected in parallel and across the secondary windings of the transformers, two stator windings being in parallel with one transformer and two with the other. Cut-outs are interposed in each of the stator circuits, and also switches. These switches

are operated with compressed air, and serve for switching off the stator circuits when the motors are not working. The controlling valves of these switches are enclosed in the controllers, and are so arranged that as soon as the controller handles are moved from the stopping position the stator switches are automatically closed. Similarly, when the controllers are moved to the stopping position, the switches are opened. Thus, whenever the motor coaches are brought to a standstill, the stator circuits of the motors are made dead, and the no-load losses in the motors are therefore reduced to a minimum.

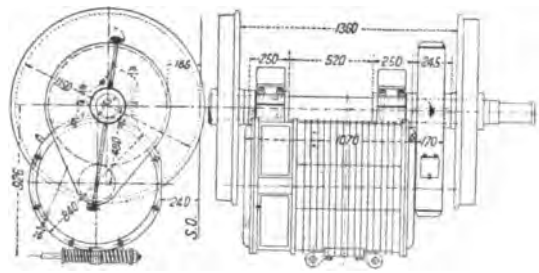


FIG. 211.—Motor and Gearing.

Although the stator circuits are broken every time the controller is turned to the off position, the main transformers still remain energised, this being desirable on account of the fact that current is needed whilst the trains are standing in the stations for working the air pump and for heating. The Westinghouse air compressor is worked by a 5-h.p. Déri motor. An automatic switch, which operates under the influence of the compressed air, starts and stops this motor, so that the pressure of the air is maintained more or less constant. The heaters, which consume 600 watts at a pressure

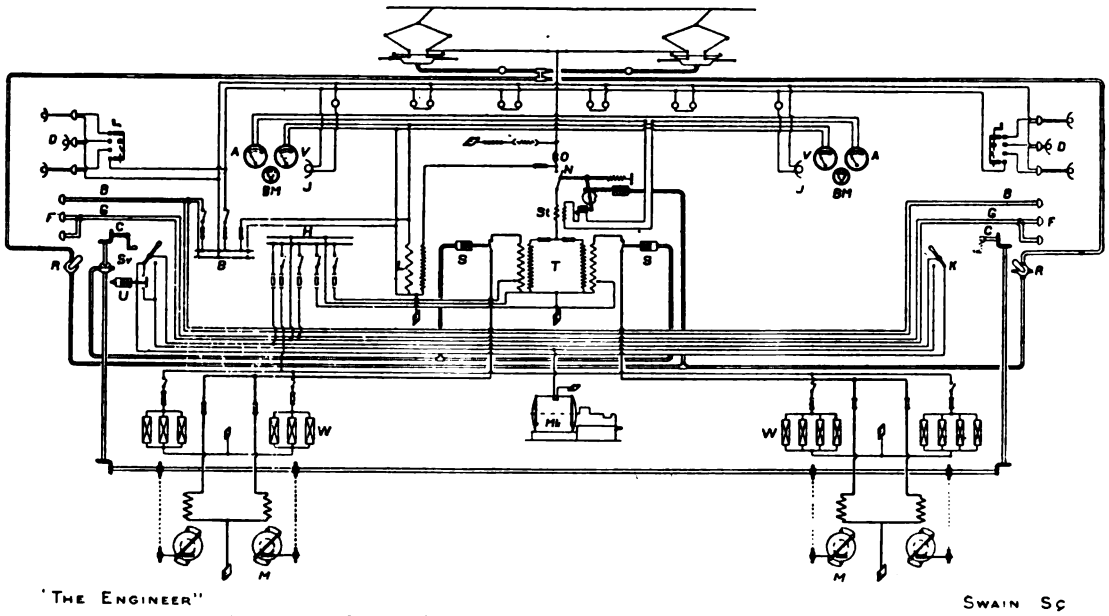


FIG. 212.—Connections for Passenger and Goods Motor Coach.

of 500 volts, are distributed in groups underneath the seats of the passenger coaches. A separate transformer is used for lighting purposes, and this reduces the 8,000 volts to 36 volts, the latter being the pressure at the lamp terminals. We will now turn to the mechanism which is used for displacing the brushes of the main driving motors.

It will readily be understood that since the only function which the controller has to perform in connection with the main electrical circuit is that of opening and closing the stator switches, the control gear is of a very simple character, and that

no trouble is likely to be met with in connection with arcing. From the illustration, Fig. 213, the general principle of the controllers will be understood. It will be seen that the act of turning the controller handles C (Fig. 212) causes a horizontal shaft, which is situated under the coach, to revolve, and this, in turn, transmits the motion to the brush gear of the various motors through the medium of a chain. The whole of the control gear is exceptionally simple, and is said to have proved perfectly reliable. The gear ratio employed is such that six revolutions of the controller shaft corresponds to a brush displacement from the point of zero speed to full speed. Moreover, owing to the fact that every precaution has been taken to reduce friction to a minimum, the controller handle can be turned with great ease, since very little power for moving the brush shafting gear is needed.

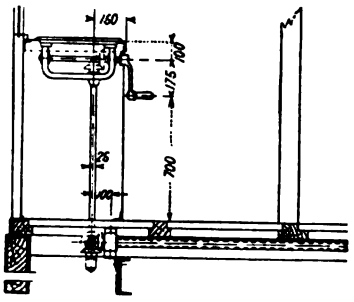


FIG. 213.—Controller.

In order that the diagram, Fig. 212, may be properly understood, reference will now be made to various lettered parts in detail. Ammeters are shown at AA, voltmeters at VV, lamps at D, plugs for use in connection with lighting the trailer coaches at F, heating connections for trailing coaches at G, compressor and heating circuits at H, lamps for instruments at J, compressor switch at K, lighting transformer at L, main motors at M, motor compressor at Mk, maximum current cut-out and emergency switches at N, inductance coil at O, valve for raising and lowering current collectors at R, stator switches for motors at S, valves for controlling these switches at Sv, brake manometer at BM, the automatic compressed air governor at U, and the heaters at W.

The weight of the complete electrical equipment amounts to about 17·8 tons, and this applies both to the passenger and goods coaches. Ever since the railway was taken out of the contractor's hands, which was in September of 1910, everything has worked perfectly satisfactorily, and the system of control adopted has met all expectations. Some doubts were expressed at first as to the advisability of adopting this system of brush displacement for controlling the speed, and those who criticised the scheme pointed out that there was a possibility of the brush displacement not being exactly alike on all the motors, and that the load would not be equally distributed in consequence. Experience has shown, however, that the brushes on the different motors move synchronously, and that the gear works quite evenly. It appears that some slight trouble was experienced at first with the bearings, but this was simply due to the use of an unsuitable lubricant; but all troubles of this kind have now been eliminated.

THE VALLE-MAGGIA RAILWAY

THE Valle-Maggia Railway (Locarno Ponte-Brolla-Bignasco) was opened in the autumn of 1907, and was the first single-phase line put into operation in Switzerland. In the streets of the town of Locarno the pressure on the track is only 800 volts, but in the open it is 5,000 volts. The periodicity is 25 cycles per second. It will be understood that this practice does not involve complications such as are met with on railways where the trains have to work on two distinct systems, and where direct current is used in the suburban area. On the contrary, the employment of two voltages simply necessitates a suitable arrangement of the primary windings on the main transformer. With a view to safety, the overhead wire in the neighbourhood of the town has been placed 6 m. above the rails, whereas on the open lines running through the country the distance between the wire and rails varies from 4.1 m. to 4.7 m.

Originally the line was worked entirely with motor coaches, each equipped with four 40-h.p. motors, and capable of drawing a 55-ton train at a speed of 40 km. per hour on the level. Owing to the increase in the goods traffic, however, the employment of a locomotive became necessary, and an order for a 250 h.p. engine was placed with the Oerlikon Company. It is capable of drawing an 85-ton train at a speed of 35 km. to 40 km. per hour on the level, and the hauling power on the draw bar amounts to 3,600 kilos. Measured over the buffers the total length is 7·45 m., whilst the length over the body is 6·55 m. The wheel base measures 3·3 m., and the height above the rails is also 3·3 m. The weight of the electrical equipment with gearing is 9·3 tons, and the total weight 20·8 tons. The gauge is 1 m.

The bow collector to be seen in the illustration of the locomotive, Fig. 214, is only used when the locomotive is passing through the town sections of the railway, whereas when it is passing through the open country the current is collected from the 5,000-volt wires by means of two rod current collectors which are fixed above each driver's platform. These collectors are to be seen in the illustration, Fig. 214, but in this instance they are lowered so as to be out of contact with the overhead wire. In Fig. 215, however, the rod collectors are shown in use, and it will be noticed that they slide along the wires laterally. The rods are made of steel tubing, and have inte changeable brass contact pieces. They are pressed on to the trolley wires by means of a spiral spring, and the rods can be raised or lowered by the hand wheel to be seen on the ceiling of the driver's compartment in Fig. 216. An interlocking arrangement prevents the collectors from making contact with the overhead wire whilst the door of the high-tension chamber is opened. Similarly, the door of this chamber cannot be opened until the current collectors are out of contact with the overhead conductor.

The bow used for collecting the current whilst the locomotive is passing through the town sections of the railway can also be raised and lowered from the driver's compartment, and whilst the locomotive is passing through the cross country the bow is locked by a safety fastening device, so that there is no possibility of it coming into contact with the wire whilst the current is being taken up by the rod current collectors fixed over the driver's cabins.

FIG. 214.—250 h.p. Oerlikon Locomotive.

FIG. 215.—Oerlikon Locomotive Hauling Train on 5,000-volt Line.

In accordance with the builder's usual practice, a geared motor is employed, the pinion of which meshes with a spur wheel on the intermediate or jack shaft. The method of transmitting the power from this shaft to the driving wheels is clearly shown in Fig. 214. The two cranks on the intermediate crank shaft are set at an angle of 90 degrees with respect to one another, and the crank shaft is driven by the motor through helical gearing having a ratio of 1 to 3·9. The gear wheels are 190 mm. wide, the diameter of the pinion being 240 mm., and that of the wheel which meshes with it 936 mm. There is a driver's compartment at each end of the locomotive, where the control gear for the 800 and 5,000 volt circuits is placed. One motor and one transformer serve for both these pressures.

Hand-operated and compressed air brakes are provided, and they act together on the four brake shoes. For the purpose of supplying compressed air to the brakes of the trailing coaches, the necessary pipe couplings are provided at each end of the locomotive, as shown in Fig. 214. The compressed air is derived from a small Westinghouse motor-driven compressor, which also provides the supply of compressed air to the sanding gear. The air containers for the brakes and sanding device are fixed in the low-tension compartment, and the pressure of air is controlled in the customary manner. An electrical brake is also fitted. The indicator to be seen in the upper part of the illustration, Fig. 216, enables the driver to ascertain the speed at which the locomotive is travelling. This instrument is placed so that it can be seen from either end of the locomotive. It will be gathered the speed indicator faces one end of the passage communicating with the two ends of the locomotive.

FIG. 216.—Driver's Compartment.

Turning now to the diagram of connections shown in Fig. 217, the current passes from the 5,000-volt trolley wire to a choking coil S, and from there to a current transformer S*th* and then to the high-tension switch O. From this switch it next passes to the high-tension winding of the main transformer T, and finally reaches earth by way of the rails. The earth wire in this diagram is marked EL. A circuit, branched off from the right-hand current collector R, serves to protect the electrical equipment from the effects of lightning, this circuit containing a lightning arrester BS, and an earthing resistance EW. The bow current collector for taking up the current from the 800-volt trolley wire is shown at the centre of the upper part of the diagram, and here again a circuit is branched off from the 800-volt wiring to protect the apparatus from lightning discharges. But this branch circuit merely contains a lightning arrester BS. The main high-tension switch for the 800-volt circuit is shown at O^1, and, like the 5,000-volt switch O, it is constructed as a two-step switch, the object being to avoid rushes of current when the circuits are first closed.

When the moving members of the switches are put in the first position, a resistance is connected in circuit, and this naturally limits the first rush of current. On moving the switch handle to the second contact, however, this resistance is short-circuited, and the transformer and motor are then directly connected across the trolley wire and rails. The high-tension switches are closed by means of a hand wheel on the wall of the driver's compartment. Relays *Re*, connected to the current transformers *Sth*, automatically release the high-tension switches O and O^1 when the current exceeds a predetermined value. As is customary on single-phase locomotives, the main oil switches may also be opened by merely pressing a button, as shown at DD, this operation completing a circuit through the relays *Re* and allowing current to pass into

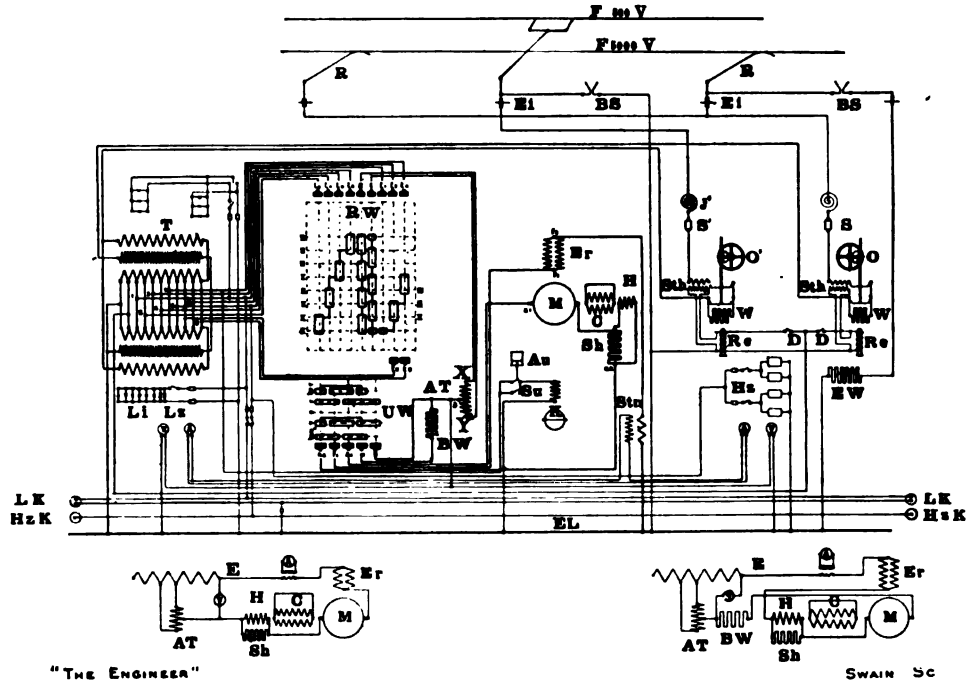


Fig. 217.—Connections of Oerlikon 250 h.p. Locomotive.

the release magnets from the current transformers *Sth*. The press button is to be seen on the wall in the illustration, Fig. 216.

To avoid mistakes the high-tension switches O and O^1 are interlocked, so that it is impossible to close them both together. The main transformer T is constructed with vertical cores, and has two primary windings, one for current at 5,000 volts and the other for 800 volts. It is a natural air-cooled transformer with a capacity of 205 kilovolt-amperes. The 800-volt primary windings are fixed close to the cores, whilst the 5,000-volt windings are situated outside the lower voltage windings. It will be seen from the diagram that the 5,000-volt primary coils of the transformer are connected in series, whilst the 800-volt coils are in parallel. Moreover, when the locomotive is working on 800 volts, the secondary windings of the transformer are connected in series with the 800-volt primary windings, so that under these conditions the transformer is working as an auto-transformer. The lower voltage or secondary windings are divided into ten sections, each giving a pressure of 29 volts. From an inspection of the diagram it will be seen that sections Nos. 2 to 10

are connected with the contacts of the regulating drum RW of the controller. The voltage is controlled in accordance with a system which the Oerlikon Company has adopted on various other electric locomotives.

Instead of the leads of the main controller RW being connected directly to the motor they are led to the two ends XY of a preventive coil AT, the middle point of which is connected to the motor through the reversing switch UW. The object of this auto-transformer or preventive coil is, of course, to avoid breaking the circuit on the main controller when the moving contacts shift from one position to another. The principle will be understood from the small lower diagram on the left of Fig. 217. Here one end of the secondary winding of the main transformer is earthed at E, and likewise one terminal of the motor. The other terminal of the latter is connected to the centre point of the auto-transformer AT, which in turn is connected to the middle of the secondary winding of the main transformer, and it is evident that if the lower lead of the auto-transformer is connected to various tappings in the secondary of the main transformer by means of the controller, the voltage at the motor terminals can be changed without braking the motor circuit. The letters on this small diagram have reference to the same parts as in the main diagram. M is the motor, E*r* the main exciting winding, C the compensating winding, H the commutation winding, and S*h* a shunt connected across this winding, whilst A is an ammeter and V a voltmeter.

FIG. 218.—Controller.

This system of control corresponds to that adopted by the Oerlikon Company on the locomotives built for the Seebach-Wettingen Railway and also for the Rhætian Railway. The controller, which is shown in Fig. 218, is fixed in a horizontal position, and is placed above the motor, and the shaft to be seen at the top in Fig. 218 runs right through the locomotive and is connected to a hand wheel in the drivers' cabins, as shown in Fig. 216. The motor is a series compensated machine with commutating poles, and has an hourly rating of 250 h.p., the speed ranging from 500 to 1,100 revolutions per minute. The casing of the motor is divided into two, so that the upper half of the stator can be lifted off and the armature removed. The stator carries three distinct windings, (*a*) the main exciting winding in series with the armature, (*b*) a short-circuited compensating winding, and (*c*) the reversing field or commutating winding. There are no resistance leads between the armature windings and commutator segments. The connecting lugs are made of copper and of ample section to avoid all heating. Many claims are made for the Oerlikon single-phase commutator motor. It is said to lie less sensitive to variations in periodicity than most single-phase commutator motors. In the case of the machine now under consideration a variation in periodicity from 14·5 to 20 cycles per second makes little difference in the commutation provided that the shunt across the commutating winding is suitably adjusted.

This was the first locomotive which the Oerlikon Company fitted with an electric braking system, but, notwithstanding, the scheme proved quite satisfactory. The motor connections which exist when the electrical braking system is applied are to be seen in the small right-hand diagram in Fig. 217, where BW is the brake

resistance. The other letters correspond to the same parts as shown in the small lower diagram on the left of Fig. 127. With the aid of this electrical braking system the locomotive can be brought to a standstill, and it will be understood that the electric brake can work without the use of line current, and that when the braking resistance short-circuits the motor, the latter becomes a dynamo and generates continuous current. This it does without the least sign of sparking. The electric brake is brought into use by the reversing drum of the controller, which has five positions, marked " stop," " forwards," " brake forwards," " backwards," and " brake backwards."

The only auxiliary machine carried by the locomotive is the Westinghouse air compressor, which is driven by a 5 h.p. repulsion motor, shown at K in Fig. 217. This motor starts and stops automatically, and keeps the pressure of the compressed air at the desired value. The automatic switch is shown at Au, but a hand-operated switch Su is also fitted, so that the motor can be put into operation by hand in the event of anything happening to the automatic gear.

For lighting and heating purposes current is taken from the main transformer at pressures of 200 to 250 volts, the lighting circuit plugs being shown at LK and those for heating at HzK. The locomotive lighting circuit is marked Lz.

THE RHÆTIAN RAILWAY

A PORTION of the Rhætian Railway has been electrified. The railway traverses the Engadine district of Switzerland, and the electric lines extend from Bevers to Schuls, from Bevers to St. Moritz, and from Samaden to Pontresina. The distance between the two first-mentioned places is 49·1 kilos., that between Bevers and St.

FIG. 219.—Eight-Wheeled Brown-Boveri Electric Locomotive.

Moritz 7·3 kilos., and between Samaden and Pontresina 5·3 kilos. The maximum gradient is 2·5 per cent., and the maximum curve radius 150 m. At Bevers there is a sub-station where three-phase current at 23,000 volts and a periodicity of 50 cycles per second is converted into single-phase current at a pressure of 11,000 volts and a periodicity of 16⅔ cycles for use on the railway. The three-phase-current is derived from the Brusio Supply Company. In this sub-station there are two 1,300 kw.

converters, connected with a fly-wheel and direct-current machine, the latter working in conjunction with a battery of 242 cells, and having a capacity of 1,268 ampere-hours. . In this way the fluctuating load of the railway is equalised, and the load on the generators in the power-house is more or less steady.

On the Bevers-Schuls line there are stations at Bevers, Ponte-Campovasto, Madulein, Zuoz, Scanfs, Cinuskel-Brail, Zernez, Süs, Lavin, Guarda, Ardez, Fetan, and Schuls-Tarasp. Switch boxes have been erected at Zuoz, Cinuskel-Brail, Zernez, Süz, and Ardez. Sheds for accommodating the rolling stock have been erected at Zernez and Schuls-Tarasp. On the line from Bevers to St. Moritz there are stations at Bevers,

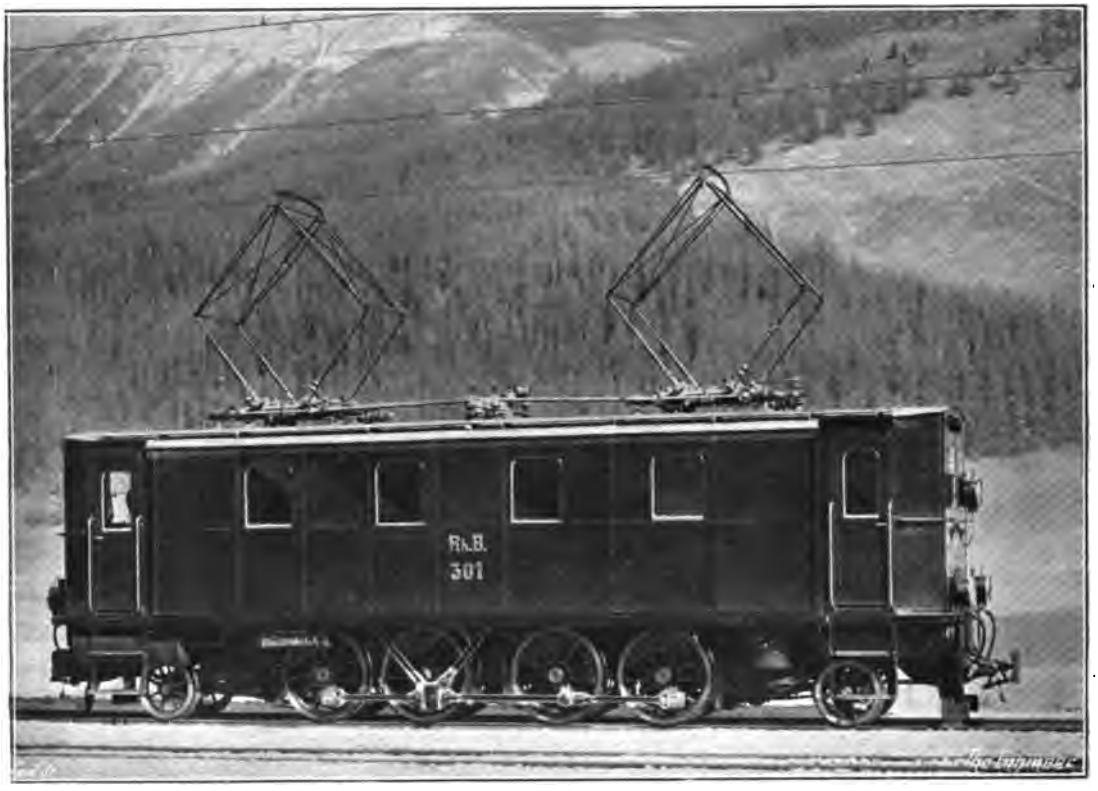


FIG. 220.—Twelve-Wheeled Brown-Boveri Electric Locomotive.

Samaden, Celerina and St. Moritz. Finally, on the line from Samaden to Pontresina there are stations at Samaden, Punt Muraigl, and Pontresina.

The general appearance of the overhead wires in the open section of the line can be gathered from Fig. 220, from which it will be seen that there is a carrying cable and contact wire. The normal length of the spans is 60 m. A simple suspension system is adopted in tunnels. The section of the copper conductor and also that of the steel-carrying wire is 80 sq. mm. For supporting the overhead wires lattice masts are used. In the stations there are cross supports, whilst in the open the masts carry iron brackets. The normal height of the contact wire above the surface of the rails is 5·5 m., the maximum height—in stations—6·3 m., and the minimum height—in tunnels and under bridges—4·15 m. The current returns to the converters by way of the rails, which are connected to the supply system by a copper conductor having a section of 100 sq. mm.

Several firms have built single-phase locomotives for this railway. Brown, Boveri & Co. supplied seven engines of the 1–B–1 type, as shown in Fig. 219, and one of the 1–D–1 type, Fig. 220. The length of the former type, measured over the buffers, is 8·7 m., and the width of the body 2·63 m. The fixed wheel base is 2,500 mm. The diameters of the driving and running wheels are 1,070 mm. and 700 mm. respectively. When ready for service the total weight of a 1–B–1 locomotive is 37 tons. Only one motor is used for propelling the 1–B–1 engines. It is a Deri motor, as used on the Martigny-Orsières Railway and on other single-phase lines. The one-hour rating of the motor is 300 h.p., this being the power available at the circumference of the wheels at a speed of 28 kilos. per hour and with 950 volts at the terminals of the motors. The motor is erected high up in the body of the locomotive, and

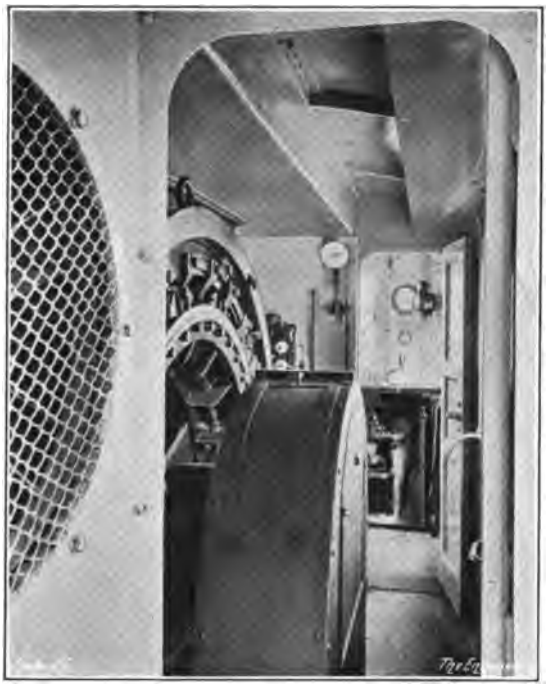


FIG. 221.—Motor Compartment.

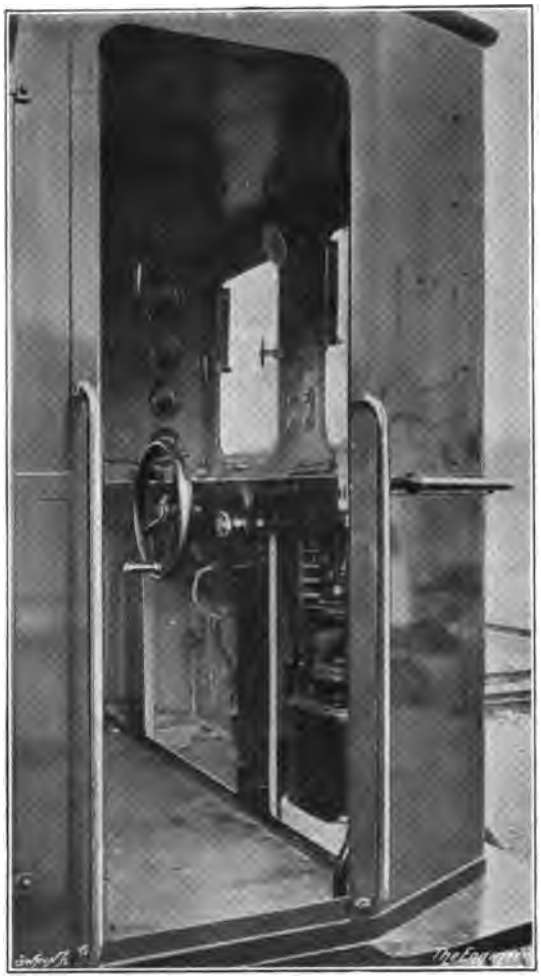


FIG. 222.—Driver's Compartment.

all troubles arising from a low centre of gravity are thus avoided. As explained elsewhere (see the Martigny-Orsières Railway), the speed of the Deri motor is entirely controlled by brush shifting, and it is therefore unnecessary to provide tappings on the secondary side of the transformer for regulating purposes. Hand and vacuum brakes are fitted to all the locomotives under consideration. Fig. 221 shows the motor and Fig. 222 the driver's compartment.

For lighting purposes a small motor generator is used which works in conjunction with a small storage battery, in accordance with the Brown-Boveri system. The

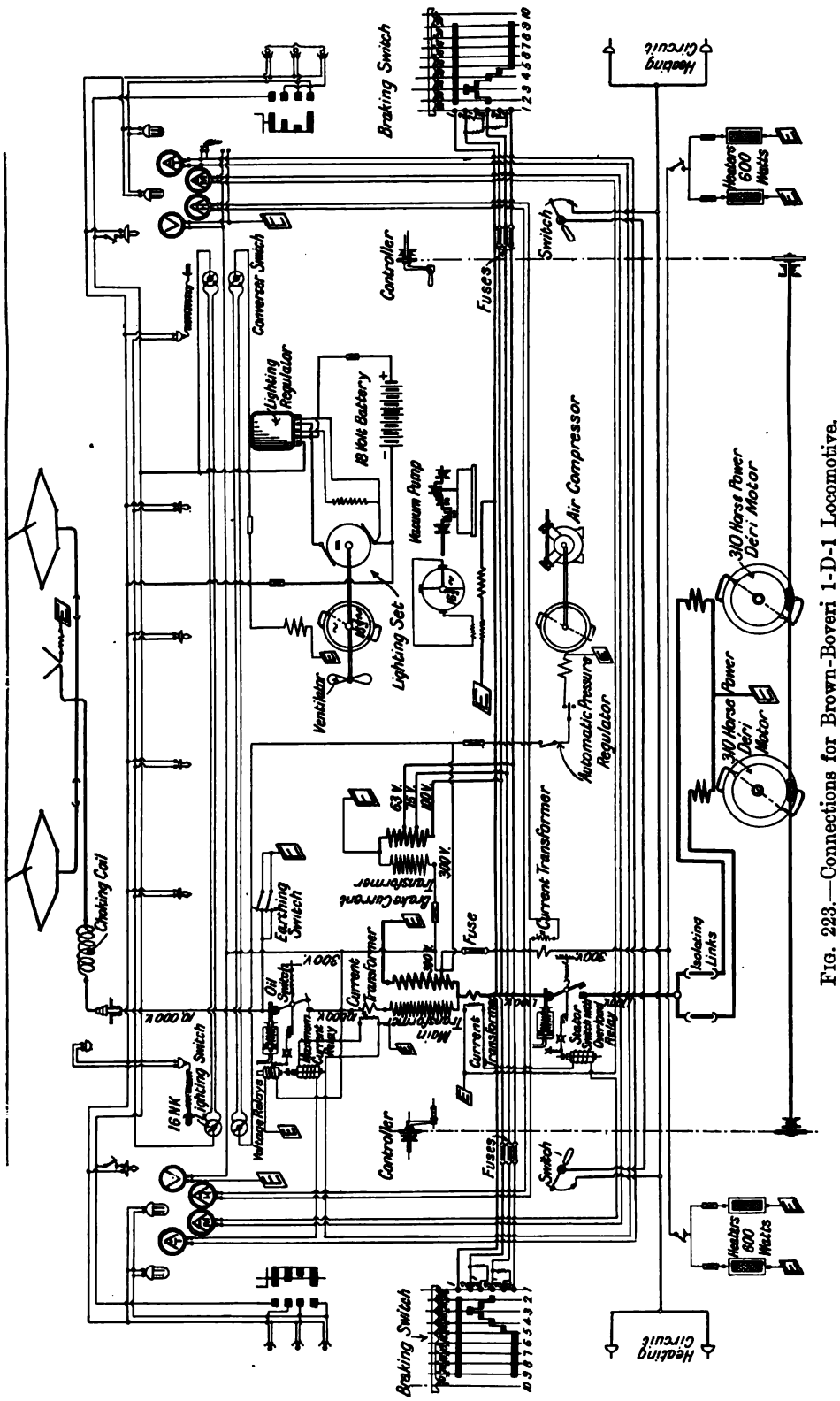


FIG. 223.—Connections for Brown-Boveri 1-D-1 Locomotive.

pressure applied to the lighting circuit is only 18 volts. Each of the driver's compartments is heated by means of an electrical heater, each consuming 300 watts. The average speed for passenger trains is 28 kilos. per hour, and the maximum speed 45 kilos. per hour. Trains hauled by these locomotives weigh 90 tons, and they are capable of carrying a load of 53 tons. As will be gathered from the illustration, Fig. 219, power from the motor is transmitted to an intermediate shaft between the driving axles, and then to the driving wheels by means of side coupling rods. There is no gearing.

Since the pressure on the overhead wire is 11,000 volts and that at the terminals of the motor only 950 volts, a transformer is necessary. It is an auto-transformer, and has a capacity of 415 kilovolt-amperes, 60 kilovolt-amperes of which is utilised for heating the train. It gives two pressures, 950 volts for driving the main motor and 300 volts for heating and other auxiliary purposes. A blower is connected to the shaft of the lighting converter, and the air from this blower is used for cooling the main motor and transformer. The current collectors, which are of the pantograph type, high and low tension switches, sanding gear, and whistles are pneumatically operated, the compressed air being derived from a small air compressor.

The electrical equipment of the 1–D–1 locomotive differs from that of the 1–B–1 type in that there are two 300 h.p. motors instead of one. A complete diagram of connections for this type of engine is given in Fig. 223. Locomotives were also built for this line by the A.E.G. Company and the Oerlikon Company.

THE LÖTSCHBERG-SIMPLON RAILWAY

WITH the opening of the line from Frutigen to Brigue on the Lötschberg Railway on June 28th, 1913, an important and difficult undertaking was completed and direct connection between Paris, Berne and Milan established. The history of this wonderful piece of work was described fully in articles in *The Engineer* for November 10th and 24th, 1911 ; and to those articles the reader should refer for details of construction and information concerning the advantages the line is expected to offer.

It is hoped that the main traffic to and from Italy will now pass through Berne, giving a larger proportion of mileage in Switzerland and less in France.

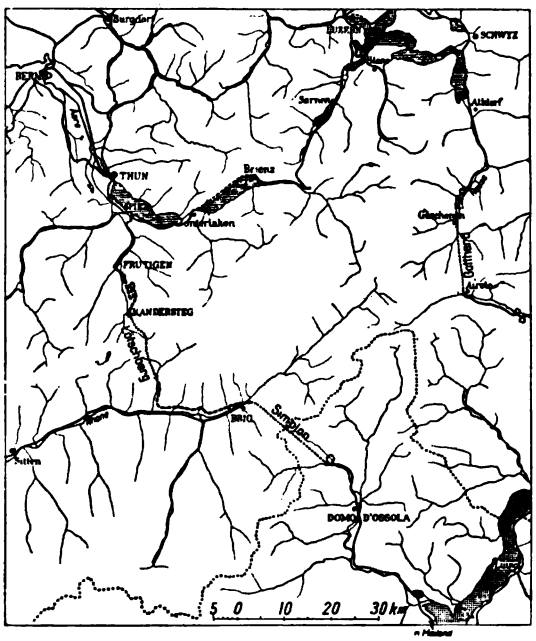


FIG. 224.—Map showing the Lötschberg Railway.

The tunnelling work through the Lötschberg was commenced on October 15th, 1906. Unforeseen difficulties were encountered during the boring operations in the Gasteren Valley, where layers of glacier rubble were met with instead of firm lime rock. A fall compelled the constructors to abandon their original course and to bore round this spot, thus making the tunnel 800 m. longer than it would have been had this trouble not presented itself. The tunnel (see maps, Figs. 224 and 225, and the profile of the line, Fig. 226) is 14·6 kms. long. It was completed on March 31st, 1911, and the next two years were devoted to the construction of the railway itself.

The track winds from Frutigen through the Kander Valley at the northern slope of the Bernese Alps, passes under them below the Lötschberg Pass to the tunnel mouth on the south slope at Goppenstein, and then follows the Lötschen Valley and along the slope of Rhone Valley to Brigue, the terminus at which it joins the Simplon line. The gauge of the railway is 1·435 m. (4 ft. 8½ in.), and the rails, which are in lengths of 12 m., weigh 42 kilos. per metre, and are laid on wooden sleepers.

For the greater part of the distance the contact line, which supplies current to the locomotives at 15,000 volts and at a periodicity of 25 cycles per second, is suspended from a simple catenary cable ; it is only on the first part of the line from Spiez to Frutigen that an auxiliary wire is used.

The chief engineering features of the line north of the main Lötschberg Tunnel are the lower tunnels, of which there are twelve, and which aggregate a total length

of 4,925 m., or one-fourth of the length of the northern approach line. Perhaps the most interesting work of all is the great double loop (see Fig. 227). It is in the form of a long-waisted 8. This spiral begins at one end in the open valley, near Mittholz, and then after returning about 4 km. towards Frutigen, ascends the second spiral loop in tunnel and turns once more direct for Kandersteg.

From Fig. 227, the cuttings, tunnels, embankments, viaducts, dumps, and gradings can be followed, and the complication of twists and turns in the serpentine portion of the line may be actually much more easily followed than upon the spot. Both the permanent railway and the contractors' railway are shown on this plan, together with the progressive kilometric distances of each, the radius of curves and the altitudes. The juxtaposition of widely varying altitudes in certain parts sufficiently explains the erratic course of the line. It was specified that the maximum gradient should not exceed 2·7 per cent. At one point near Fürtin three railway lines, all proceeding in reversed directions, are actually staged one above the other.

The southern portal of the Lötschberg tunnel is shown in Fig. 228, and the ventilating house at the northern portal in Fig. 229. Fig. 230 shows the Blausee-Mittholz Station, and Fig. 231 the Kandersteg Station.

Let us now turn to the electrical equipment of the Spiez-Frutigen line, which constitutes an approach to the Lötschberg Railway, and which was acquired by the Bernese Alpine Railway Company in 1907. It is a standard gauge line, and is approximately 13·5 km. long, the steepest gradient being 1·55 per cent. The Lötschberg line running from Spiez to Brigue is about 75 km. long, and its steepest gradient is 2·7 per cent. At Brigue (see map, Fig. 224) the Lötschberg Railway joins the Simplon line, thus forming a portion of the railway connection between Paris, Berne and Milan through the Simplon.

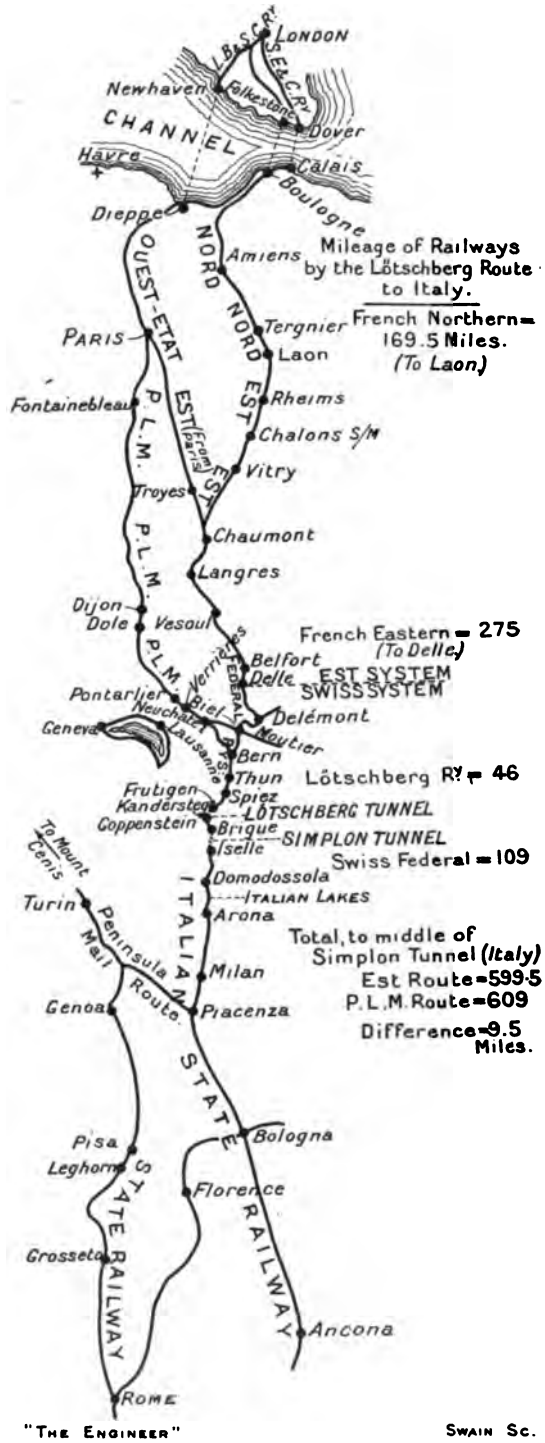


FIG. 225.—The Lötschberg Railway and its Connections.

With the opening of the Lötschberg line, the Spiez-Frutigen section assumed the character of an international railway. The line between Spiez and Frutigen is equipped with multiple suspension overhead lines, constructed in accordance with the designs of Siemens-Schuckert. On the sidings at the stations, however, a simpler form of overhead equipment has been adopted. As the Siemens-Schuckert overhead construction has been dealt with in connection with various lines that have been described, it need not be considered in the present instance. The motor coaches, however, are of special interest. At the end of the year 1908 the Bernese Alpine Company gave an order for three single-phase motor coaches and two 2,000 h.p. locomotives. The former are used mainly for local service on the Spiez-Frutigen section, but are also used on the Lötschberg line as far as Kandersteg The locomotives, on the other hand, are for dealing with goods traffic between Spiez and Frutigen, but they are specially designed for running to Brigue on the Lötschberg

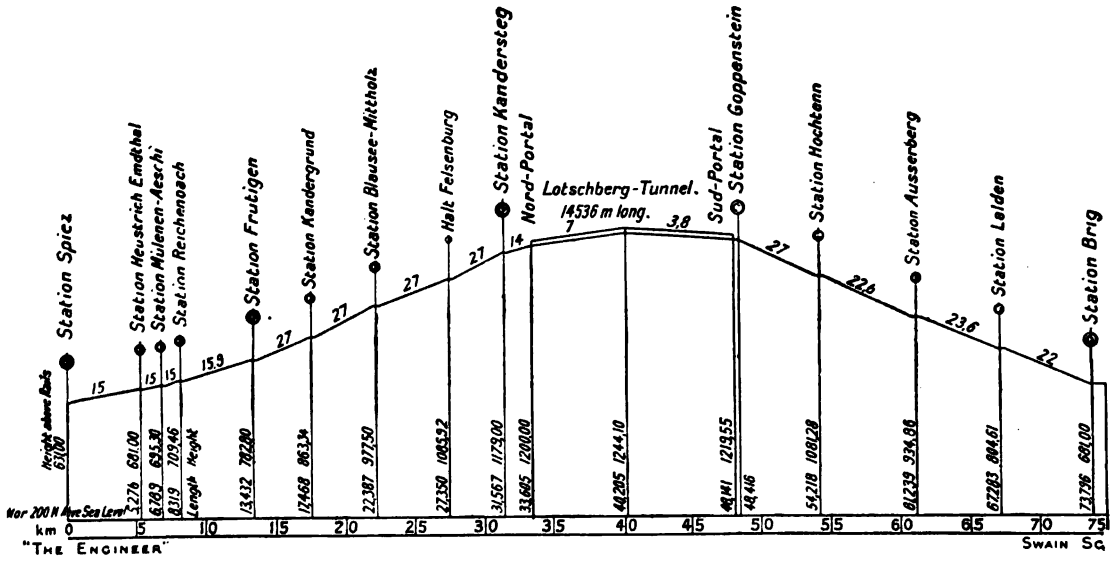
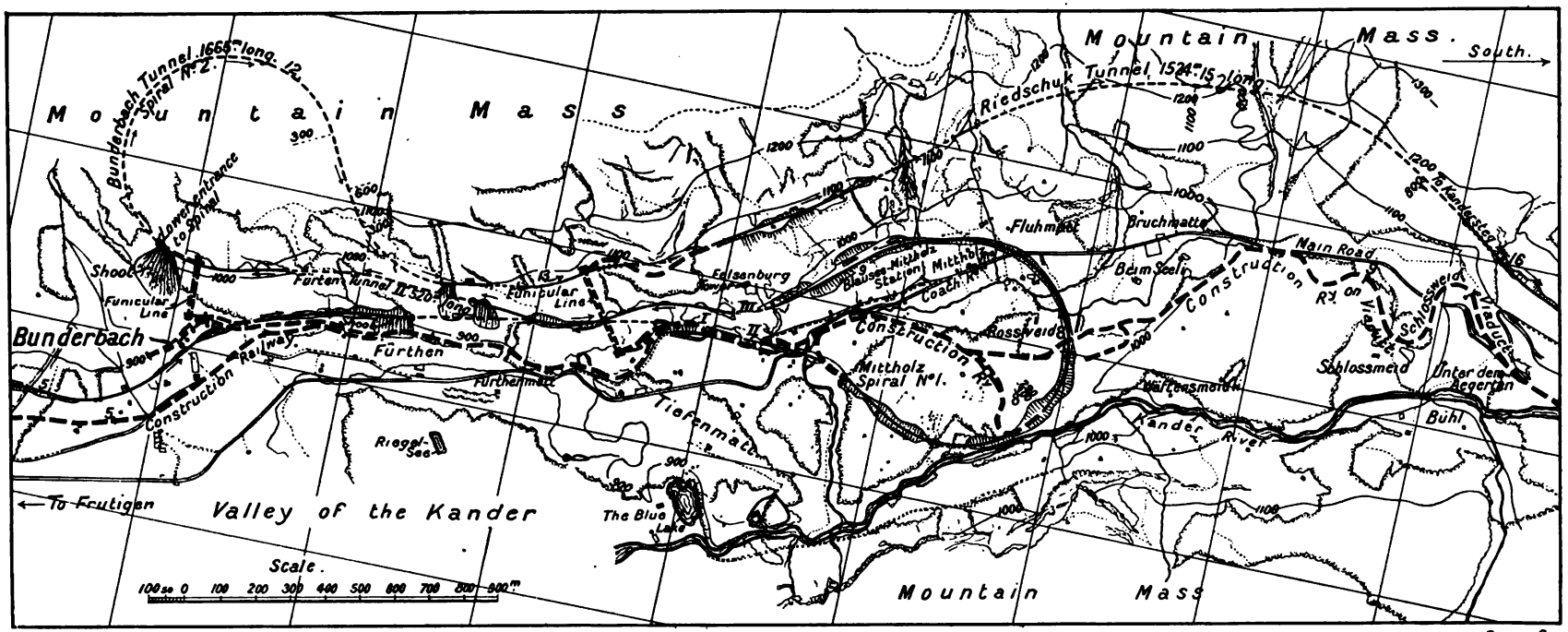


FIG. 226.—Profile of the Lötschberg Railway.

Railway, and are consequently built as heavy mountain locomotives. The pressure on the overhead conductor is 15,000 volts, and the periodicity 15 cycles per second.

The Siemens-Schuckert motor coaches, as shown in Figs. 232 and 233, are of the four-axle type. There are two large third-class compartments, each containing about thirty-two seats, two driver's compartments at the ends of the coaches and a lavatory in the centre. The coaches have a total length between the buffers of 20·3 m., and the breadth gives sufficient space for the provision of four cross seats and a central corridor.

Each bogie, as shown in Fig. 234, has two motors, which are geared to the driving axles. The ratio of the gearing is 1 : 3·45. Each motor is rated at 230 h.p. for one hour, so that the total capacity of a coach amounts to a little over 900 h.p. The normal running speed is 45 km. per hour, and the maximum speed 70 km. per hour. The tractive effort when all the motors are in use and at a speed of 45 km. per hour is 5,000 kilos., and the maximum tractive effort at starting 7,400 kilos., measured at the circumference of the driving wheels. With all the motors in use a motor coach is capable of drawing a 240-ton train on a 1·55 per cent. gradient at a speed of 45 km.



"THE ENGINEER" SWAIN Sc

FIG. 227.—Double Loops on the Frutigen-Kandersteg Portion of the Lötschberg Railway.

FIG. 228.—The Southern Portal.

FIG. 229.—The Ventilation House at the Northern Portal.

FIG. 230.—Train at Blausee-Mittholz Station.

FIG. 231.—Kandersteg Station.

per hour. For the Spiez-Frutigen line, however, two motors provide sufficient power. The coaches are fitted with the usual hand and air brakes, the former being so con-

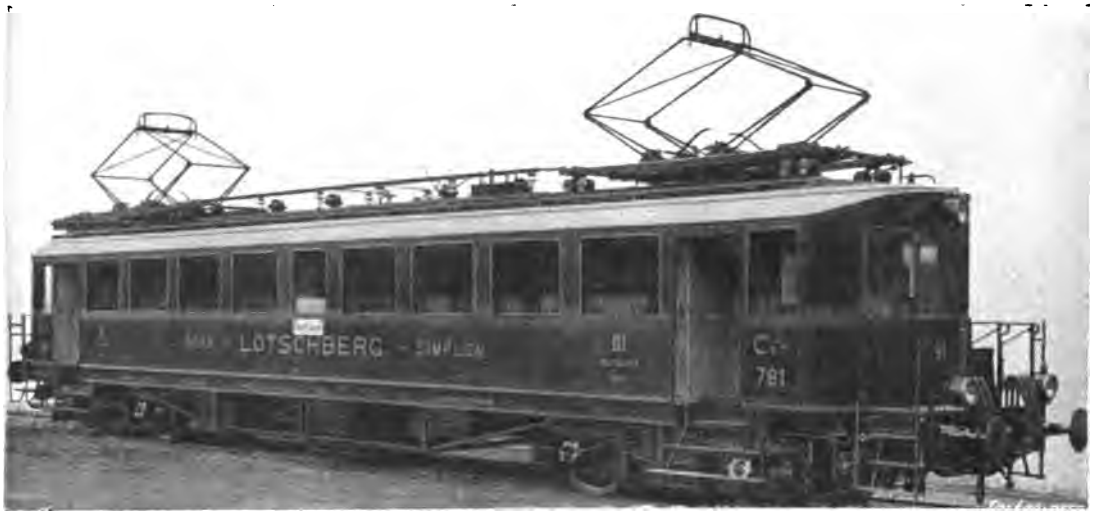


FIG. 232.—Motor Coach for the Lötschberg Railway.

structed that the brake spindle in each of the driver's cabs only controls the brakes on the bogies next to the respective cabs. The Westinghouse air brake gear comprises a

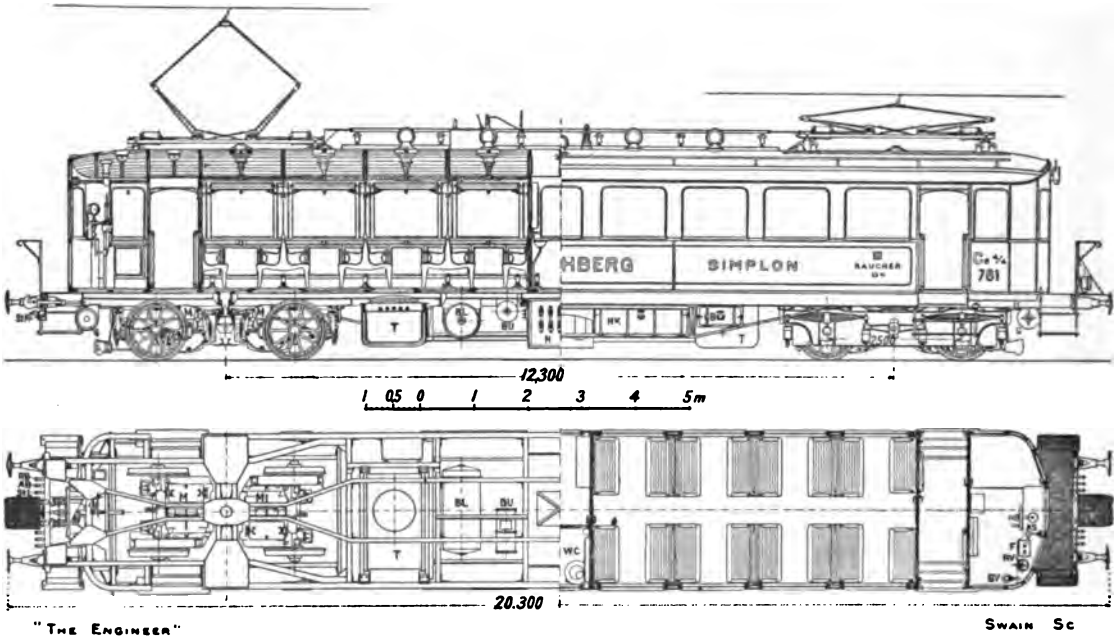


FIG. 233.—Motor Coach for the Lötschberg Railway.

quick action brake and a governing brake, the latter being provided for use on long steep inclines. Each bogie has its own brake cylinder, the piston of which operates on eight brake blocks. Each wheel is also equipped with sanding gear worked with

compressed air. The brake equipment will be understood from Fig. 235. The air is compressed by an electrically driven piston pump, which is hung under the coach. The driver's cab contains the usual electrical control gear, the Westinghouse brake valve, the air escape valve, the hand brake wheel, the valves for operating the

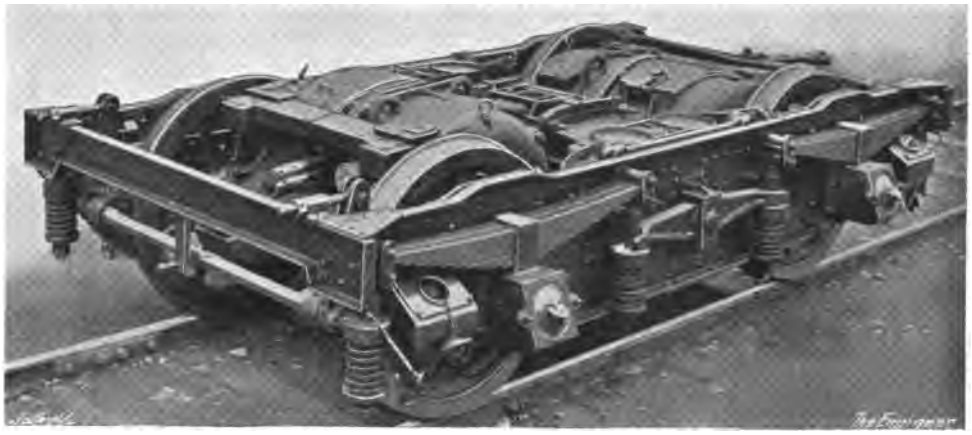


FIG. 234.—Bogie for Single-Phase Motor Coach, Lötschberg Railway.

sanding gear and the whistle. On the back of the cab there is a switchboard, on which switches are mounted for controlling the train lighting and heating, etc.

A diagram of connection for one of the Siemens-Schuckert motor coaches is given in Fig. 236. The current collectors are shown at AA, B is the lightning arrester, C intermediate resistance, D the choking coil, E earth, F the earthing switch, G the high-pressure oil switch, H the high-pressure resistance, J the transformers, K the contactors, L reversing contactors, M_1, M_2, M_3 and M_4 motors, N auxiliary turns on transformer, O preventive coil for preventing the low-tension circuit being broken as the main contactors change the connections, P current transformer, Q maximum current relay, R coach heaters, R_1 heaters for sanding gear, S high-tension cut-out, T air pump, U ventilating motor, V motor cut-out, W signal lamps, X driver's cab lamps, Y coach lamps, *a* ampere meter, *b* voltmeter, *c* controlling switch for contactor current, *d* current controlling resistance, *e* main controller switch drums, *f* auxiliary drums (the function of which will be described later), *g* reversing switch, *h* main air reservoir, *i* air conduit, *k* brake pipe, *m* pressure gauge, *n* brake cock, n_1 governing brake valve, *o* small air cock on air pressure chamber, p^1 hand lever for oil switch, *q* solenoid for actuating oil switch, q_1 relay, s_1 main lighting switch, s_2 switch for internal lig ting, s_3 switch for driver's cab lamps, s_4 switch for signal lamps, s_5 wall plugs for signal lamps, s_6 switch for blower, s_7 main switch for heating, s_8 another switch for heating, s_{10} main switch for controlling current circuit, s_{11} switch for blower and air pump, s_{12} multiple switch for cutting off motors, s_{13} switch for cutting off motor No. 1, s_{14} switch for cutting off motor No. 2, s_{15} hand switch for air pumps,

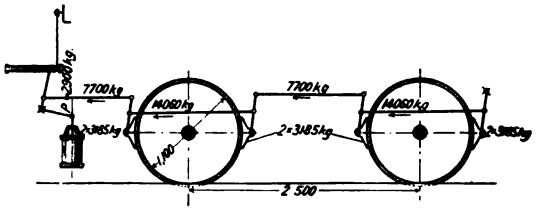


FIG. 235.—Diagram of Braking Arrangements.

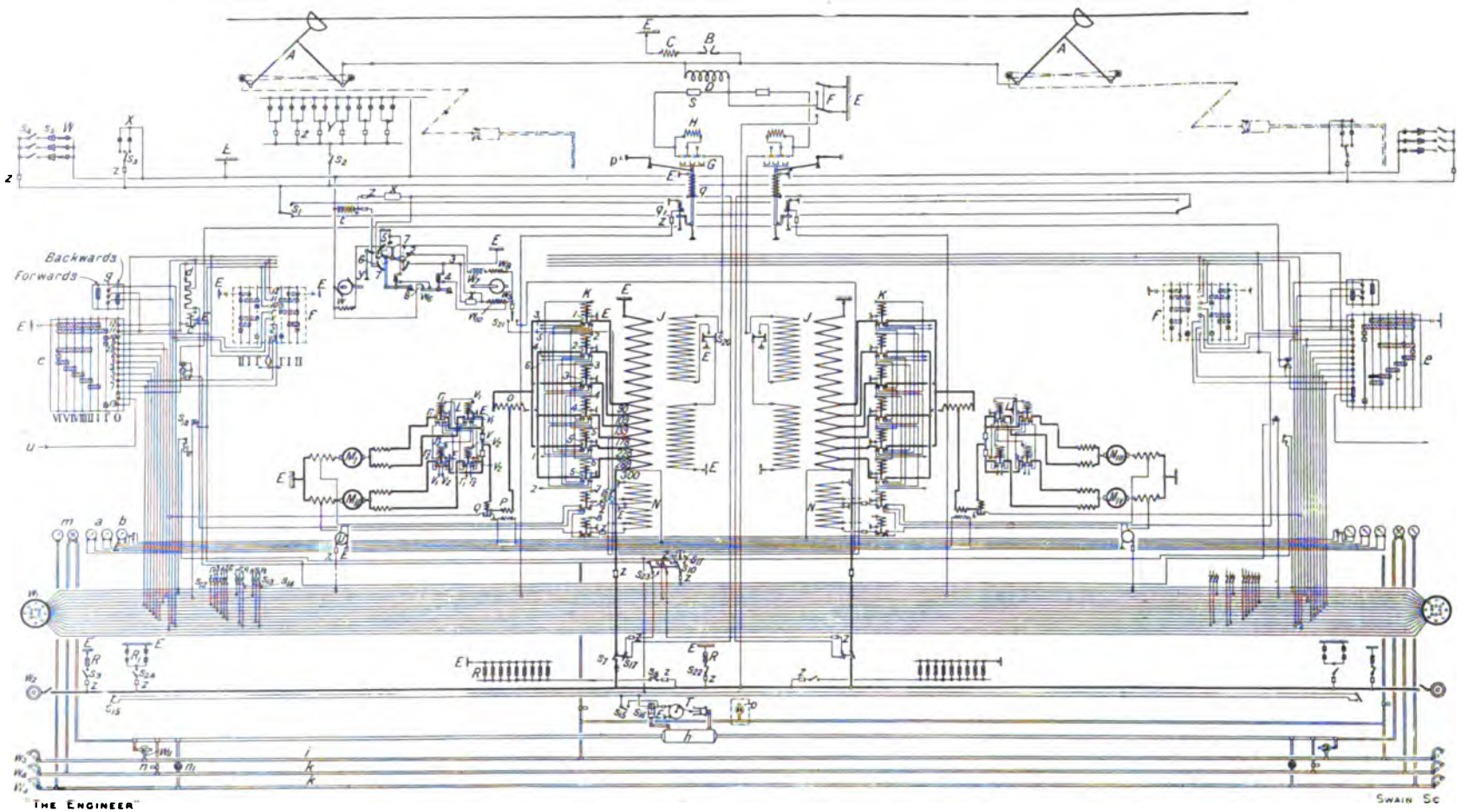


FIG. 236.—Diagram of Connections of Motor Coach, Lötschberg Railway.

s_{16} automatic pump switch, s_{17} circuit breaker for oil switch coil, s_{18} push button for opening oil switch, s_{20} switch for changing the primary connections so as to enable the coaches to work with two different voltages, s_{21} switch for motor generator, s_{22} switch for lavatory heating, t storage battery, w_1 coupling box for the control mains, w_2 coupling plug for the heating mains, w_3 air pressure coupling for current collector, w_4 air pressure coupling for the automatic and governing brake, w continuous-current dynamo, w_6 automatic change-over switch, w_7 induction coil for phase splitting, w_8 auxiliary winding, w_9 induction motor, w_{10} excitation winding. Other details need not be referred to.

It will be gathered that the electrical equipment is divided into two separate and distinct sections, and there is a transformer for each group of motors. It has been stated that for the Spiez-Frutigen line two motors are sufficient, and this system of dividing the electrical equipment into two distinct sections enabled the coaches to be fitted with two motors in the first instance and the remaining two to be added later. Since the periodicity is only fifteen cycles per second, it has been necessary to use a motor generator set and battery for the purpose of lighting the coaches.

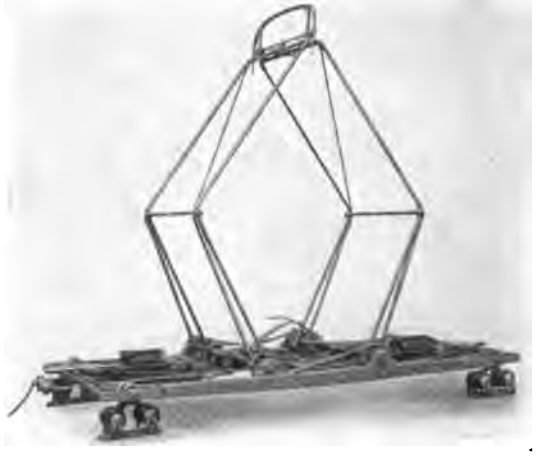


FIG. 237.—Current Collector.

The current collectors are of the Siemens-Schuckert type. From the illustration, Fig. 237, it will be seen that they rest on a frame supported on high-pressure insulators. The sliding contact piece is made of aluminium and has two grooves which are filled with grease or other lubricating substance. In accordance with the usual practice, the bow is raised by means of compressed air cylinders, two being provided for each bow. The construction is such that the pressure on the bow is approximately the same in all positions and amounts to about 3·5 kilos. When the collector is in its lowest position it lies very low down in the frame, as will be seen from Fig. 233. Since the air cylinders are connected with the live parts of the collector, an insulating tube is interposed in the air supply pipes. The current collectors are controlled by means of a cock in the driver's compartment. To enable the driver to operate the current collectors in the event of the air pump breaking down a hand pump is fitted in each motor coach.

The lightning arresters fitted to the motor coaches for the purpose of protecting the transformers, etc., are of the horn type and, as will be seen from the diagram, Fig. 236, they are connected in circuit with a large resistance which is immersed in oil. It consists of forty-eight carborundum bars having a total resistance of 2,900 ohms. Owing to the exceptionally high pressure used on the overhead line the high-tension switches break the circuit in four different places. They are oil switches and can be actuated by the coil q from the driver's cabins. Moreover, in order that the current may not be applied to the transformers suddenly, the switches are fitted with an auxiliary contact which introduces the resistance H into the high-pressure circuit. When the switch is completely closed, however, this resistance is short circuited. The high-pressure switch is opened by the relay q_1, which is energised by the press

button S_{18} in the driver's compartment. In cases of emergency the switch can also be opened by means of the lever p^1. All the high-pressure apparatus is placed in a special chamber under the centre of the carriages. The mica insulated high-pressure line passes from the roof of the carriage through the lavatory and thence to the high-pressure compartment. The latter can only be opened when the bow is lowered clear of the overhead line.

It is impossible to raise the current collectors whilst the door of the high-tension chamber is opened. Each transformer has a capacity of 450 kilovolt-amperes on the one hour basis, and serves for two driving motors and auxiliaries. The transformers, Fig. 238, are of the oil type, and the windings are enclosed in a corrugated iron case. They are hung under the coaches in such a manner that all sides of the cases are exposed to the air, and in this way efficient cooling results. It will be seen from the diagram that the primary windings of the two transformers are in two parts, and by means of the switch s_{21} they can be arranged for working with a pressure on the overhead line of either 15,000 or 7,500 volts.

In accordance with the scheme adopted by Siemens-Schuckert on other railways, the secondaries of the transformers are provided with two auxiliary coils N which are connected to the compensating windings of the motors. There are ten main contactors for each transformer, of which six are used for varying the voltage and the remaining four for reversing. The contactor switches marked 7 and 8 deal with the connections for the auxiliary turns N. The motors are eight-pole series type fitted with reversing poles, and are air cooled. The diagram of connections shows that in accordance with the usual practice preventive coils O are used in the secondary circuit of the transformers, which prevent the current from being interrupted when the contactors change the secondary connections. From the middle point of these coils the current passes to the measuring transformer P over the current relay Q, the cut-outs V, and the reversing contactors L to the motors. The current used for auxiliaries is also taken from the transformers, likewise the controlling current, at a pressure of 178 volts. Switch s_{10} controls this circuit. The air blast motors, which are controlled by the switch s_{11}, are worked at a pressure of 109 volts, as is also the motor for driving the lighting set, whilst the current for heating is supplied at a pressure of 300 volts.

FIG. 238.—450-Kilovolt-ampere Transformer.

The control of these motor coaches is carried out in much the same way as on other coaches built by the firm of Siemens-Schuckert. In order to obtain controlling current in the first instance the first high-pressure switch is closed by means of continuous current from the storage battery. This is effected by turning one of the controllers e to the first position I. The other high-pressure switch is then closed by means of alternating current. In this position I all the initial connections to the motors are also made. An additional drum f has been fitted, which is connected in parallel with the main switch drum e. This is for the purpose of obtaining a low travelling speed. The two drums are actuated by the same hand lever, which can only be removed when the main drum of the controller e is in the stopping position. A blower is provided for each pair of motors and the air passes through a flexible rubber pipe. The blower motors can be switched off at will from the driver's compartments.

It is customary to put the blowers out of action in the tunnels owing to the moisture in the air, but in order to keep the motors cool the blowers remain in operation when the train stops. The air pump for the brakes is driven by an 8 h.p. series motor through the medium of tooth gearing. An automatic switch controls the starting and stopping of the air pump motor in accordance with the pressure of air in the reservoir. Provision is also made for controlling the motor by hand. Two groups of radiators are placed under the seats, and these are controlled from the driver's compartment. There are eighteen radiators in the passenger compartments and twenty-one in the whole motor carriage. They each consume about 500 watts, so that the whole motor carriage can be heated with about 10·5 kw. A 100-watt radiator is also used in connection with the sanding apparatus. The heaters in the trailer coaches are connected up by wires with plug sockets at the end of the coaches. Electric energy for heating purposes up to 100 kw. can be supplied throughout the train. The heating current is taken from both transformers and the radiators are connected to the 300-volt tappings.

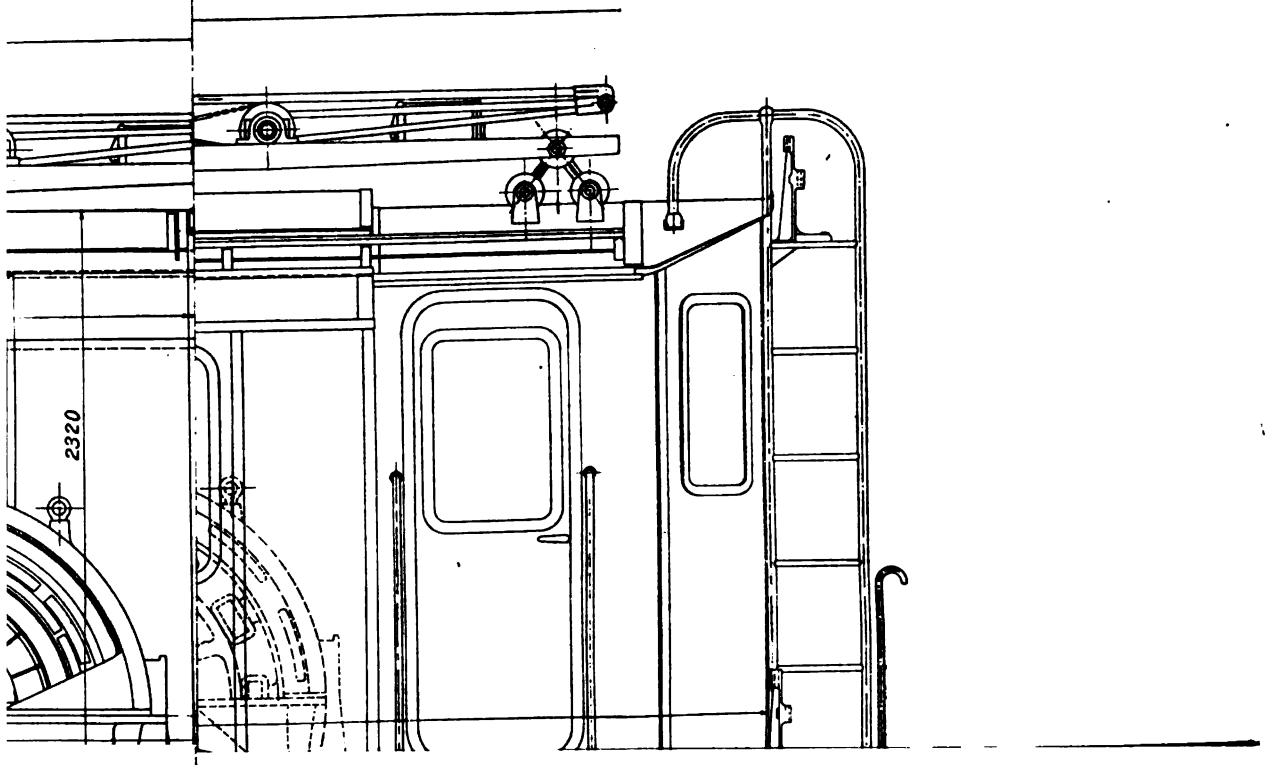
A single wire is used for the heating circuit, the return being through the metal work of the coaches. The lighting converter has a capacity of 1·2 kw., and it works in conjunction with a storage battery having a capacity of 81 ampere-hours. The motor w_9 of the converter is of the induction type and is started by means of a phase-splitting device. With the aid of the change-over switch s_{21} it can be connected to the 109-volt tappings of either of the transformers. The instruments in the driver's compartment comprise a speed indicator, ammeter and voltmeter, which latter, by means of a change-over switch, can be connected to the low-tension windings of either of the transformers. For the quick action and governing brakes the ordinary manometer is provided.

A very fair idea of the arrangement of the electrical equipment will be gathered from the plan and longitudinal section of one of the motor coaches shown in Fig. 233. AB is the coupling for the automatic brake, AS the emergency switch, B the brake reservoir, BU the lighting converter, BV the quick-action brake valve, F the controller, H the high-pressure chamber, HB the hand brake, HK the contactor switch box, MM motors, RB the coupling for the governing brake, RV the regulator valve, STL the coupling for the control main, and T the transformer.

So much for the motor coaches: now let us turn to the Oerlikon locomotives. Some three years ago Dr. H. Behn-Eschenburg undertook experiments with the Oerlikon single-phase engines. They had a capacity of 500 h.p., and were capable of running at a speed of 40 km. per hour, and were fitted with two single-phase motors. At that time these motors were the most powerful the firm had built. In connection with these trials, some difficulty appears to have been experienced on account of the influence of the alternating current on telegraph and telephone lines, but these troubles were soon overcome, and Dr. H. Behn-Eschenburg then drew up designs for larger locomotives, which had a capacity of 900 h.p., and the motors were built on similar lines to those of the locomotives just mentioned. At that time the possibility of building large single-phase commutator motors was doubted in various quarters, but it appears that these motors proved quite satisfactory, and since then the Oerlikon Company has built others of still greater capacity.

In 1909 the Berner Alpenbahn Gesellschaft ordered a locomotive having a capacity of 2,000 h.p. for the Lötschberg Railway. This engine, which will be described presently, is provided with two 1,000 h.p. single-phase motors. It proved so satisfactory that the consulting engineers to the Lötschberg Railway ordered twelve more, which have a still greater capacity. The design, however, does not correspond

FIG. 239.—Locomotive No. 121.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entirely with that of the first engine. Some of these locomotives were built in the works of Brown, Boveri & Co., to the designs of the Oerlikon Company, the first-mentioned firm acting as sub-contractors. Each new locomotive has a capacity of 2,500 h.p., and runs at a normal speed of 50 km. per hour, and is capable of developing a tractive force of 18,000 kilos. The maximum speed is 75 km. per hour.

It will be noted that in nearly all the locomotives so far dealt with the power is transmitted to the driving axles without the aid of gearing, but the Oerlikon Company advocates the use of higher speed motors. The gears which the company has adopted on all its recent locomotives have proved quite satisfactory, and the wear is negligible. The use of tooth gearing has not been found to result in a great reduction in the total weight, but it naturally reduces the size and weight of the motors. A motor rated at 1,000 h.p. for one hour, as used on the first-mentioned Lötschberg locomotive, weighs 9·5 tons with gearing, whilst a motor for the new locomotives weighs 14 tons. Slower speed 800 h.p. motors, as used on some of the locomotives previously described, weigh 14 tons. The efficiency of the gearing used with the Oerlikon motors is said to be 98 per cent.

Dr. H. Behn-Eschenburg has come to the conclusion that repulsion motors are notably inferior to the series type, not only with respect to efficiency, but also with regard to speed regulation and commutation. The Oerlikon Company, like various other electrical manufacturers, has adopted the series motor on all its locomotives. The experiments which Dr. H. Behn-Eschenburg has carried out have led him to conclude that there is less danger of breakdown on large locomotives equipped with geared motors than exists when slower speed motors are employed without gearing. From time to time a great deal has been said with regard to the high cost of upkeep of alternating commutator motors, but judging from Dr. H. Behn-Eschenburg's statements the motors fitted to the Lötschberg locomotives are every bit as satisfactory as direct-current motors. The brushes of the motors are said to serve for a run of 20,000 km.

The following description applies to the first 2,000 h.p. engine in its original form. After it had been in work for some time Dr. H. Behn-Eschenburg invented a new control system, and it is now used on all the Lötschberg locomotives. Nevertheless a brief description of the original control system will be given first. The engine is illustrated in Fig. 239, and a drawing is given in Fig. 240. The contract for it was undertaken by the Oerlikon Works, Oerlikon, where the electrical machinery was made, whilst all the mechanical part was placed in the hands of the Swiss Locomotive Works at Winterthur.

As the engine has to draw heavy loads up gradients which at places reach 2·7 per cent., it has naturally to be of considerable horse power, and it is therefore fitted with two motors, each of which can develop 1,000 h.p. These motors are mounted on two independent six-wheel bogies, all wheels of which are coupled. The total weight of the engine is 90 tons, making the actual load 15 tons. It will thus be seen that the locomotive is a very heavy and powerful machine indeed.

The duty prescribed for this engine is that it shall haul a load of 310 tons up a gradient of 1 in 38 at a speed of 42 km., say, twenty-six miles, per hour; or a train of 500 tons up a gradient of 1 in 64 at the same speed. In view of these requirements it was decided to give the engine a horse-power of 2,000 and a tractive force at the coupling of 10,000 kilos.—about 22,000 lbs.—whilst on the inclines a tractive effort of 13,000 kilos.—about 28,650 lbs.—or over can be developed. The greatest speed obtainable is 70 kms., say, forty-four miles, per hour, and the engine takes curves

of 180 metres radius, whilst, as said above, the axle load does not exceed 15 tons. The general particulars are tabulated below :—

Gauge	1·435 m. (4 ft. 8½ in.)
Length over buffers	50 ft.
Width	9 ft. 9 in.
Wheel base	38·5 ft.
,, ,, of bogies	13 ft. 2 in.
Diameter of driving wheels	52½ in.
Weight of mechanical part	46 tons
,, electrical part	44 tons.
Total	90 tons
Adhesion weight	90 tons
Maximum axle weight	15 tons
Weight of bogie without motor	18·5 tons
,, motor and gearing	9 8 tons
,, transformer	5 5 tons
Gear ratio	1 : 3 25
Normal speed	42 km. per hour
Maximum speed	70 ,,
Normal tractive force at coupling	22,040 lbs.
Maximum tractive force at coupling	28,650 lbs.
Adhesion coefficient at maximum tractive force	1 : 5·3
Voltage on line	15,000 volts
Periodicity	15

As already said, the mechanical part of the engine was made by the Swiss Locomotive Works, at Winterthur. The bogies, which are shown in Figs. 241 and 242, are built up of steel plates held together by stout transoms. The axles are carried on plate springs fitted with compensating gears. Firmly built in with the frames is the driving motor and its spur reduction gearing. The wheels of the latter are 255 mm. (10 in.) broad and 447 mm. (17½ in.) and 57 in. diameter, giving a ratio of 1 : 3·25. The spider of the motor is forged from a single piece of steel and is pressed on to the axle with a load of 40 tons. The gearings were cut from Siemens-Martin steel by Citroen's of Paris. They have three rows of teeth inclined at 45 degrees to each other, and with rounded corners at the junctions. The larger wheel is placed immediately below the motor, and is fitted with cranks set at 90 degrees to each other, and counterbalanced, and these cranks drive the coupled wheels through the medium of coupling rods about 8 ft. 9 in. long.

The iron body rests upon the two bearers on the bogies, which are held together by a longitudinal beam. On this beam all the heavy electrical machinery is carried, whilst the walls of the body are called upon to take little or no load. The body is divided by iron partitions into three parts, a machine room in the middle and a driver's compartment at each end. The footboard is of iron covered with pitch pine and linoleum. The compartment for the transformer and high-tension apparatus is closed by a trellis which can only be opened when the collector bow is lowered.

The driving compartments are accessible from both sides and from doors opening on to the end platforms. From the latter folding ladders lead up to the roof, it being arranged, in order to avoid accidents, that as soon as the ladders are adjusted for use valves open and allow the air to escape from the collector bow cylinders, at the same time sounding a whistle.

A Westinghouse air brake and hand brakes are fitted. Each bogie has its own cylinder, and the brake lever of each driving platform only put the brakes on the corresponding bogie. There are six brake blocks to each bogie. The air is compressed by an electrically-driven piston pump.

The electric equipment is, in its main essentials, divided into two symmetrical groups of apparatus. An entirely diagrammatic sketch of the original arrangements

is given in Fig. 243. High-tension current is collected by the bows from the overhead conductor. It passes first of all through a choking coil and is then led to an automatic

FIG. 241.—Locomotive Bogie and Motor.

high-tension circuit-breaker, after which it passes to two transformer switches, each of which is connected to one terminal of the high-tension winding of one of the two main transformers. The other terminals of the high-tension windings are connected to the wheels and then to earth through an instrument transformer. A circuit in

FIG. 242.—Locomotive Bogie and Motor.

parallel with the foregoing, which is taken off the main circuit close to where the current enters the vehicle, but does not include the self-induction coil, is connected to one terminal of a lightning arrester, the other terminal of which is connected to a resistance of about 3,500 ohms, which in its turn is connected to earth.

The current collecting bows (see the drawing, Fig. 244, and the view, Fig. 245) were supplied by the Siemens-Schuckert Company, and are of the articulated parallelogram type. They are designed for a contact line varying in height from 4·8 metres to 7·05 metres—say, from 15 ft. 9 in. to 23 ft.—above the surface of the rails, but can be lowered to 14 ft. 9 in. above the rails, so as to come well below the conductor line at its very lowest point. The width of the bow at right angles to the direction of travel is just under 4 ft., which permits of a variation from the centre line of the

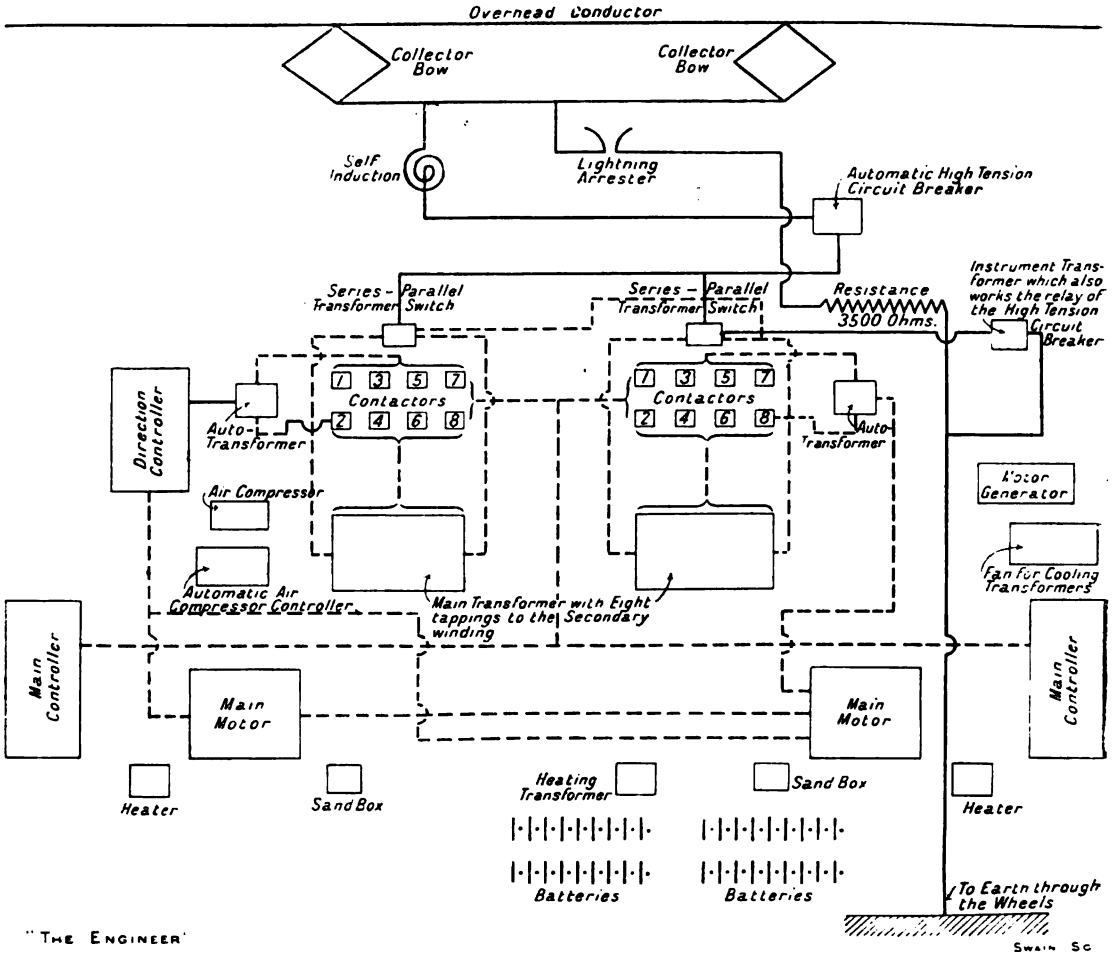

Fig. 243.—Simplified Diagram of Connections for Original Control System.

conductor wire of not more than about 15 in. The rubber is fixed to the parallelogram by a small bow, which can move independently of the parallelogram. It is made very light so as to enable it rapidly to respond to any irregularities in the line. The actual rubbing surface is of aluminium, and it is furnished with two lubrication grooves. The parallelogram is lifted by means of two cylinders worked with compressed air, the pressure of the bow on the wire being about 3·5 kilos., say, 7¾ lbs., for all heights. As the air cylinders are in contact with high-tension current a tube of porcelain has been introduced in the pipes leading to them so as to provide insulation. A valve for controlling the current-collecting mechanism is placed within reach of the driver both in the front and back driving compartments. The com-

pressed air is only used for raising the apparatus, which falls back by its own weight when the air is allowed to escape from the cylinders.

The automatic high-tension circuit-breaker works in an oil bath. It is provided with an auxiliary contact which inserts a resistance in the circuit just before it is closed. The opening and closing of this switch is ordinarily effected from the driving compartment by an electro-magnetic device worked by continuous current, but it is also fitted with maximum and minimum relays which automatically break the circuit should the voltage for any reason become in excess of that permissible or should the current fail entirely. The switch can also, should the need arise, be worked by hand by means of a key.

The two main transformers, a view of one of which is given in Fig. 246, are designed for a normal continuous capacity of 1,000 kilovolt-amperes when cooled by air forced through them. Their efficiency is given as being higher than 95 per cent. for all

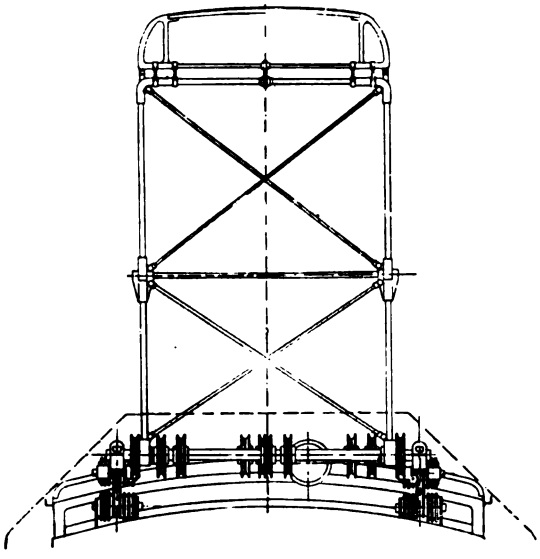

FIG. 244.—Current-Collecting Bow.

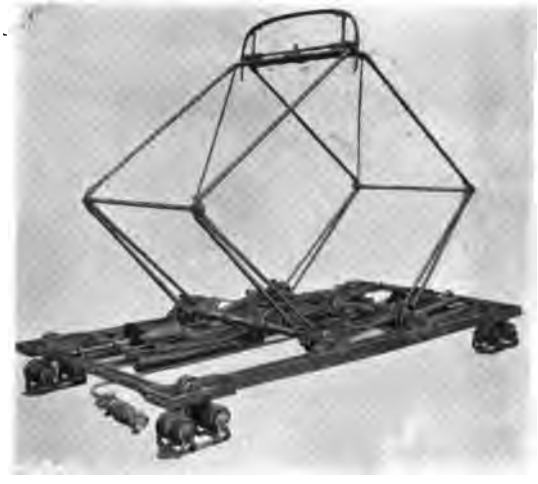

FIG. 245.—Current Collector.

loads between 200 and 1,300 kilovolt-amperes. They provide the current for the traction motors as well as for all the auxiliary machines and for heating. Their cores are arranged horizontally and are placed one above the other. The low-tension winding on each core consists of external and internal cylindrical bobbins, the whole series of windings being divided into eight sections. Between these bobbins is wound the high-tension or primary winding. The latter is divided into two parts, which can be connected up either in series or parallel. The locomotive could thus be worked on a 7,500-volt circuit instead of the 15,000 volts at which it will ordinarily operate. The eight sections of the low-tension winding are so arranged that the following voltages can be obtained: 105, 157, 210, 262, 315, 367, and 420.

We now come to the original control system. Eight terminals were fitted, one to each section, and each terminal was connected to a contactor, of which there was a series of eight mounted on the top of each transformer. These are shown diagrammatically in the sketch, Fig. 243, and may be seen also at the top of the transformer in Fig. 246. They were actuated by the main driving controllers. In the sketch there is, for simplicity's sake, only one cable connecting the controller and the contactors, but

as a fact there actually were nine wires, one being connected to the corresponding terminal of the windings of each contactor magnet, a separate wire being led to the other terminals of these magnets. By this means the driver could arrange how

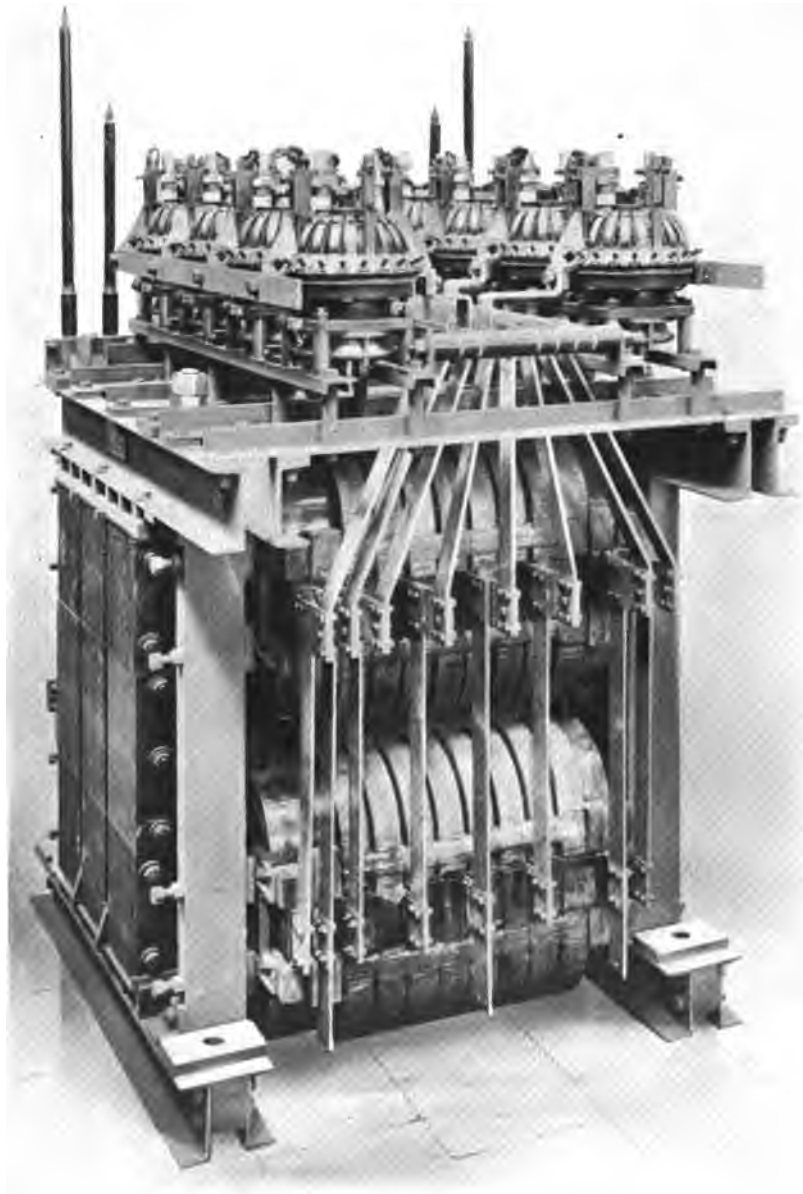

FIG. 246.—One of the Main Transformers.

many sections of the transformer were to be in circuit, and hence the voltage to be applied to the main driving motors. The contactors were arranged in two series of four each, the contactors in rotation being connected, not to the transformer winding

next to it but to that next but one to it. Thus, if we number the contactors from 1 to 8 they would be arranged as follows :—

Contactor	1	..	3	..	5	..	7
Connected to section	1	..	3	..	5	..	7
Contactor	2	..	4	..	6	..	8
Connected to section	2	..	4	..	6	..	8

Contactors 1, 3, 5 and 7 formed one group and contactors 2, 4, 6 and 8 another group. In each case the four corresponding terminals were connected together and

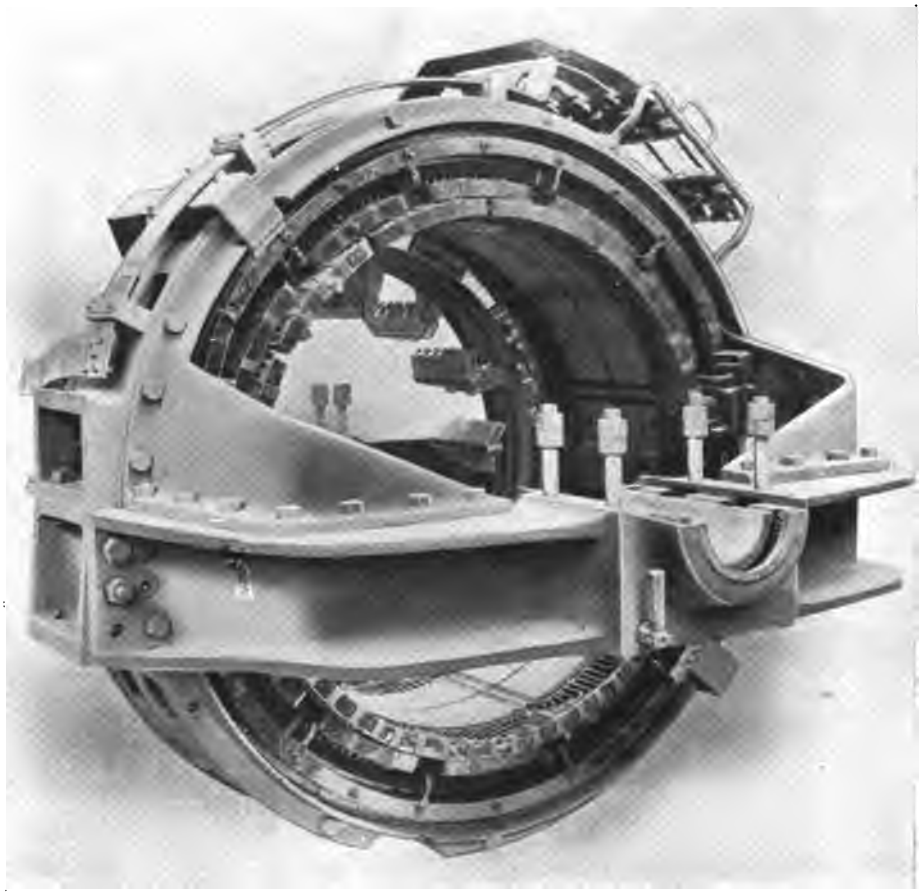

FIG. 247.—Motor with Armature Removed.

also to one side of an auto-transformer, the contactors 1, 3, 5 and 7 being joined to one end of it and contactors 2, 4, 6 and 8 to the other end. The centre point was connected through a direction controller to the motors.

The contactors were worked by continuous current. They were so connected that they only operated in predetermined order, and in the event of one of the contactors failing to act at its proper time it was forced to do so by the contactor coming next in order. Short-circuiting of the transformer coils was thus obviated. Except in the first position, when only one contactor was closed, there were always two consecutive contactors, one in each group, in circuit and connecting the transformer coils in series with the auto-transformer, from which the current then

passed to the motor. In this manner the circuit was never broken, and no short-circuiting took place when the main controller passed from one speed stud to another. The contactors were provided with renewable contacts and electro-magnetic blow-outs, and all wearing parts could be readily replaced.

The continuous current for working the contactors was derived from the battery or from a motor generator, the battery being installed so that the current should always be available. The direction controller, which could either be operated

FIG. 248.—Armature.

by continuous current or by hand, was of the ordinary cylindrical form. The new control system will be described later.

The motors, which have twelve poles, are of the Oerlikon compensated series type with interpoles. The shaft of the toothed wheel can be regarded as being the shaft of the motor itself. Views of the stator and rotor are shown in Figs. 247 and 248. The carcases of the motors are made of cast steel, in two parts, and the top portion of the stator can be lifted so as to give access to the rotor. Ample provision has been made for ventilation, so that air has access on all sides to the iron, the winding and the commutator, even when use is not made of the ventilating fan, which is installed for cooling the transformers. Without this help the hourly rating of the motor is 1,000 h.p., but with it this power can be developed continuously.

There are three windings on the stator. First there is that which is destined to provide the main magnetic field and which is in series with the armature. Then

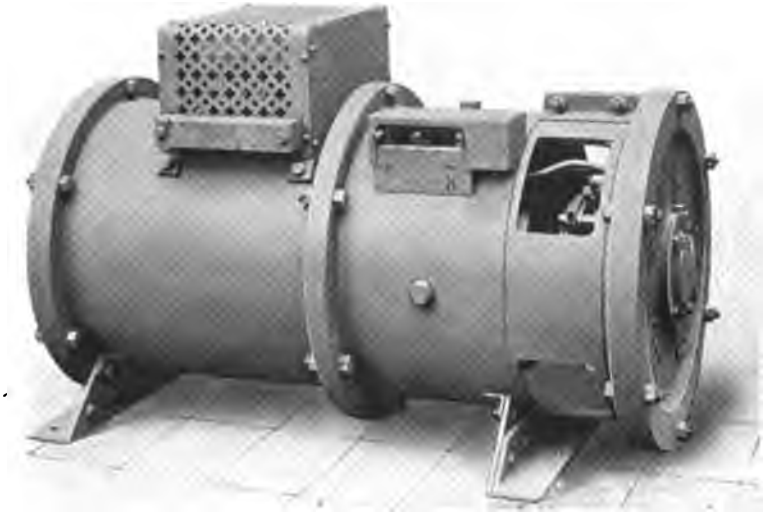

FIG. 249.—Motor Generator Set.

there is the compensating winding, the object of which is of course to counteract the field set up by the armature. These windings are made up of copper ribbons insulated with mica, fixed at uniform distances apart in the half-closed slots of the stator. The axes of the two windings are placed at half the polar distance from one another. The third or commutating winding is arranged inside the compensating windings. They are in two adjacent open slots, and hence only embrace a single tooth.

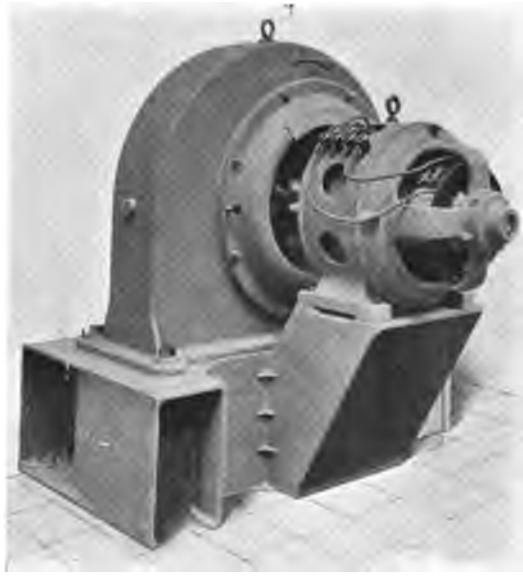

FIG. 250. – Motor-Driven Fan.

The magnetic field of the motors is calculated to allow of starting up with full tractive effort without exceeding a pressure of 4 volts between the segments of the commutator, so that no injurious sparking takes place at the brushes, which only bear on at most three segments at a time. As will be seen in the view of the rotor and its driving pinion, Fig. 248, the slots are cut obliquely. This provides a means of avoiding the higher harmonics in the pressure curve, as was demonstrated during the trials on the Seebach-Wettingen line. The use of resistances between the collector segments and the armature windings has been avoided ; indeed, the dimensions of these connections have, on the contrary, been considerably increased so as to obtain as solid a connection and as high a current-carrying capacity as possible. Trials have shown that

FIG. 251.—Air Compressor.

the efficiency of the motors does not fall below 90 per cent. down to half load, and for higher speeds than 30 km.—say, seventeen and a half miles—an hour, the power factor is above 0·95.

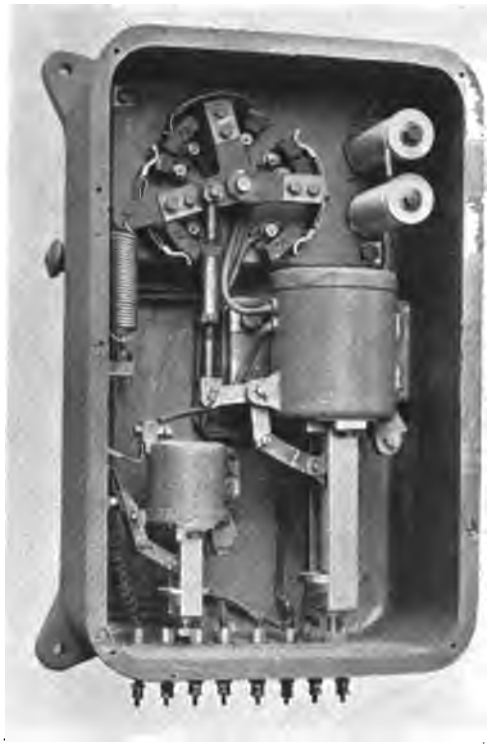

FIG. 252.—Automatic Switch.

The brush holders are carried in a ring which is provided with a toothed rack all round its periphery, so that it can be completely revolved by means of a small pinion. This is convenient not only for adjustment purposes, but because the lower brushes are readily accessible for inspection and renewal, which, as will be gathered from the illustrations, would not otherwise be possible.

The air gap of the motor is 3 mm., and as the thickness of the anti-friction metal in the bearings is only 2 mm., the rotor, even if the whole of the anti-friction metal were worn away or melted out, could not come into contact with the stator.

The starting of the locomotive is brought about in the following manner :— If the two collector bows are lowered, one of them is raised, use being made of a hand air pump in the event of the compressed air contained in the reservoir not being sufficient for the purpose. The automatic high-tension circuit breaker can then be closed by means of a switch in the driving compartment. This, however, cannot be done until the direct current control circuit is closed by means of another switch which acts in conjunction with a valve

in the compressed air circuit. Although the control system referred to above has now been altered, continuous current is still used for controlling purposes. When the two motions just mentioned have been performed the main transformers are excited and the air compressor, ventilating fan and motor-transformer, hereafter to be more minutely referred to, can be started up. When running, the first and third

FIG. 253.—Interior of Driver's Compartment.

of these three plants do not require controlling, as they are regulated automatically. The second collector bow can then be raised by turning an air valve into the position marked "Haut." This accomplished, the locomotive is ready to start. The first thing to be done then is to see that the direction switch, which actuates the direction controller, is in its proper position. Lights then indicate to the driver in which direction the engine will move. Not till the direction switch is turned from a central position either to that for forward or backward running can the main controller

be worked. With the original control system its action when revolved was to energise in rotation the various contactors connected to the section terminals of the main transformers, thus allowing current to have access to the motors. When it was required to stop the locomotive the contactors were de-energised by revolving the main controller in the reverse direction. If it was desired to open the main circuit

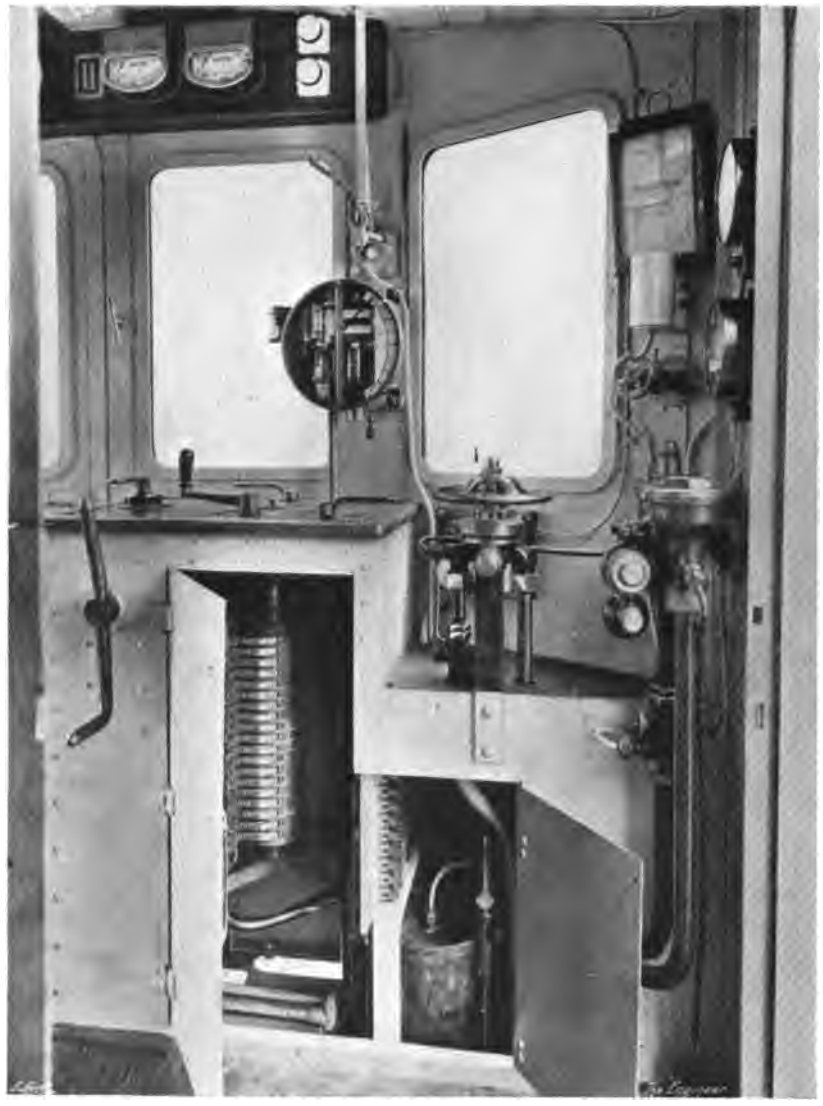

FIG. 254.—Interior of Driver's Compartment.

suddenly it was necessary either to open the main high-tension circuit-breaker or to break the control circuit. In the latter case, of course, the contactors, having nothing to hold them closed, would automatically open. When either of these methods was employed it was not possible to close the circuits again until the main controller had been brought back to its zero point. It was possible to cut any contactor out of circuit if so desired.

Let us now turn to the various auxiliaries in the locomotive, to some of which

reference has already been made. First of all there is the small motor generator set, a view of which is given in Fig. 249. This has a capacity of half a kw., and it works in conjunction with a battery of accumulators having a combined capacity of 81 ampere-hours. This little generating plant furnishes the current for lighting and for the working of all the electromagnets in the control system of the locomotive. It starts working automatically and puts itself in parallel with the battery as soon as the high-tension current reaches the main transformers. The charging of the battery is also quite automatic.

The air for cooling the transformers, and if need be the main motors as well, is supplied by a low-pressure Sulzer fan, which is driven by a single-phase series motor (see Fig. 250). The air is drawn in from the machinery compartment and is discharged into a trunk which passes along the side wall beneath the floor, and is split up into two

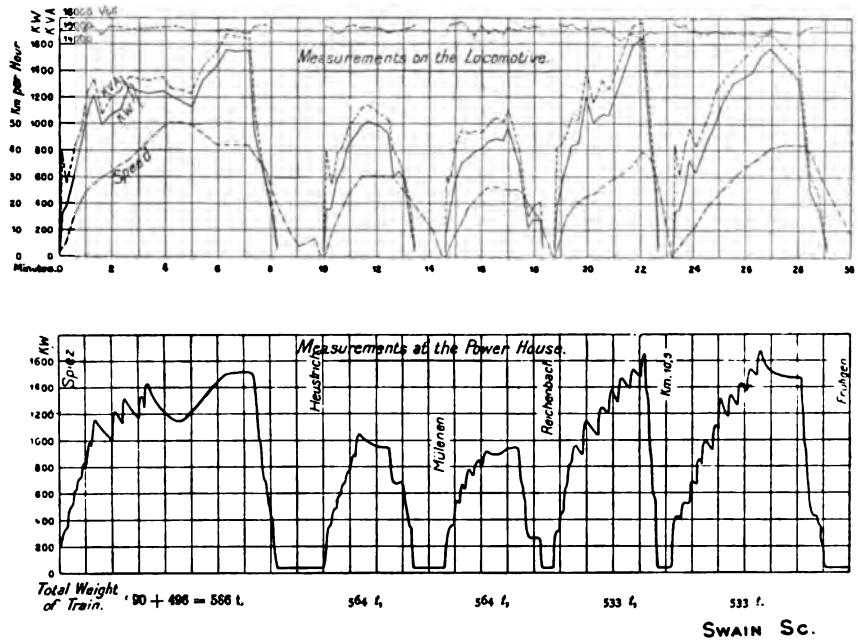

FIG. 255.—Records of the Trial Run.

ducts, which are led up to the transformers. Two further connections are made to the motors.

The air necessary for working the current collecting bows, the Westinghouse brakes, the whistles, and the sand ejectors is supplied by the small plant illustrated in Fig. 251. This is composed of a Westinghouse compressor driven through gearing by means of a 9-h.p. single-phase series motor. This group also starts itself automatically, a switch closing the circuit when the air pressure is below a certain value and opening it when the pressure is more than is required.

The battery was installed in order that the lighting should be steady and not subject to the inevitable variations in intensity which are brought about when no battery is used, by reason of the oscillations in the contact wire and current-collecting apparatus. It was considered, too, that it is just when the main line voltage fails, should this occur from any cause, that light is most needed. The voltage employed is thirty-five.

The alternating current motor of the motor generator set is worked off one of the

main transformers. At starting the generator is disconnected from the battery and lamps, which latter are run from the battery only. When, however, the generator has been run up to speed a relay works a special form of switch, shown in Fig. 252, which makes the necessary connections for the battery to be charged. The same motion that brings this about inserts a resistance in the lamp circuit. The relay is worked by a fairly strong current, but as soon as the switch has been actuated this current is much reduced by a resistance being inserted in the circuit. The switch also short-circuits the starting resistance in the motor field circuit and disconnects the auxiliary field. As soon as the supply of current is cut off from the motor a single current relay cuts off the current from the direct current relay, and a spring immediately brings the switch into its original position, which breaks the generator circuit and short-circuits the resistance in series with the lamps, at the same time putting the connections in the proper positions for restarting the motor.

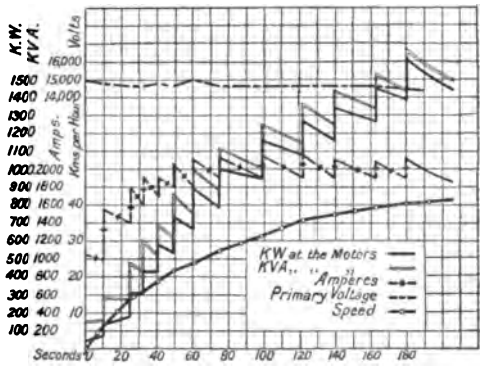

FIG. 256.—Test Curves.

For heating the locomotive, which is brought about by current at 300 volts taken from one of the transformers, three radiators which absorb 500 watts each have been installed in each driving compartment. The sand boxes are also heated by radiators which each absorb about 100 watts. For heating the train a coupling is provided at each end of the locomotive, which can transmit energy up to 100 kw.

It will not be necessary to specify in detail all the different measuring instruments which have been fitted in the locomotive, nor to explain how these are connected to the circuits. It will suffice to say that provision is made for measuring voltage current and watts wherever it is necessary, and that two Hasler registering tachometers have been fitted. Two views inside one of the driving compartments are given in Figs. 253 and 254.

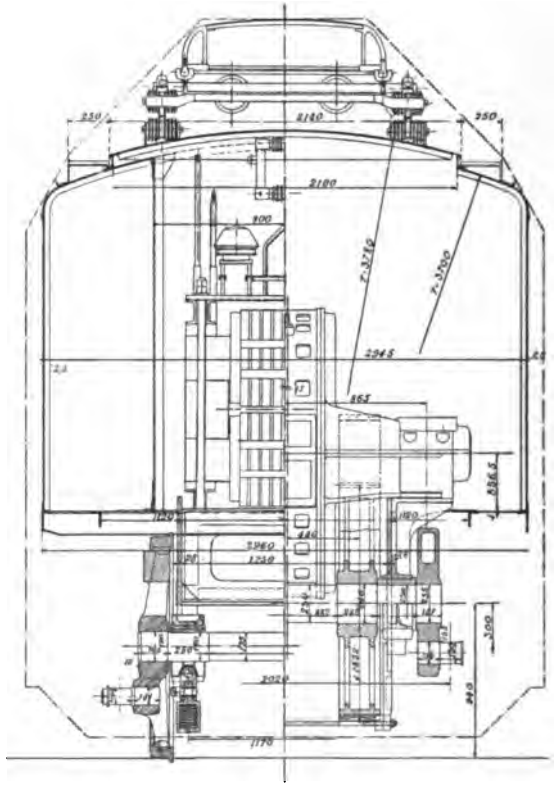

FIG. 257.—Section showing Motor and Gearing.

As a result of numerous trials, it has been proved that the locomotive can develop 2,000 h.p. continuously at 42 km. per hour and with a drawbar pull of 13,000 kilos.—say 12·8 tons. The frequency of the 15,000-volt current can vary from 13 to 17 periods per second without interfering with the working of the motors. The tractive effort at starting rises to 14·76 tons.

The following details are abstracted from a report made on this locomotive by Monsieur L. Thormann, consulting engineer to La Société du Chemin de fer des Alpes Bernioses. It is stated that neither the gearing nor the connecting-rods have given any trouble at all. It is true that the engine does not adapt itself very well to curves at speeds above 60 km. per hour, though it was designed for a maximum of 70 km. per hour. This speed has been attained during the progress of the trials, but the front bogie of the engine enters curves badly, which is attributed principally to the inertia of the mass of the motor which is mounted directly on the bogie. In addition to this

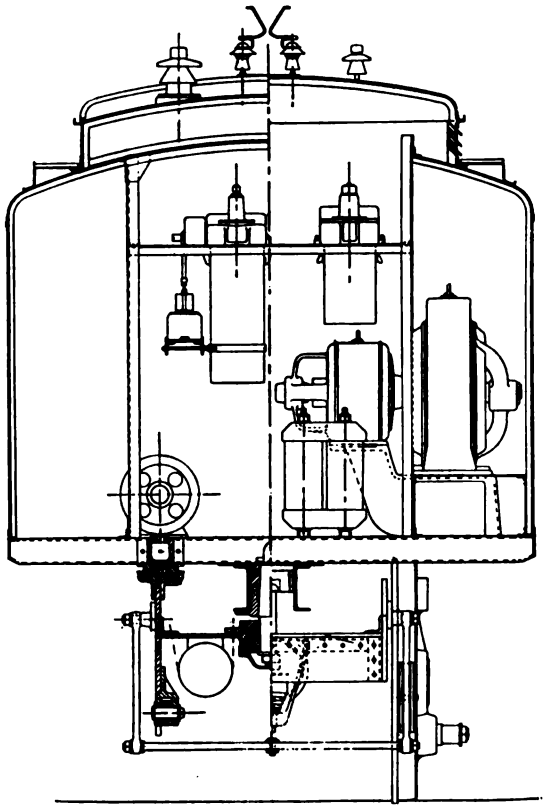

FIG. 258.—Section showing Motor and Fan.

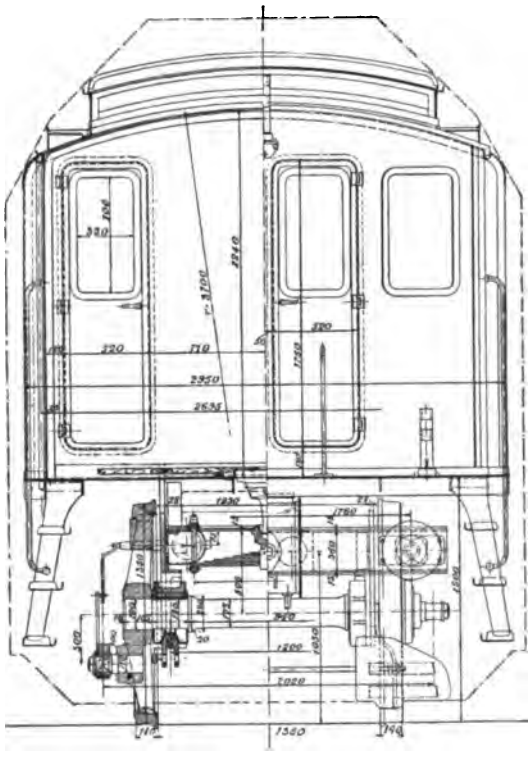

FIG. 259.—Section through Bogie.

the resistance to motion of the locomotive rises rapidly with the speed. As a result of a series of tests it has been ascertained that the resistance to motion at various speeds, the action of the air being taken into account, is as follows :—

	Km.-tons.
At a speed of 10 km.	4·3
,, ,, 30 km.	5·2
,, ,, 50 km.	8·0
,, ,, 60 km.	12·0

or omitting the action of the air :—

At a speed of 10 km.	4·2
,, ,, 30 km.	4·5
,, ,, 50 km.	6·1
,, ,, 60 km.	9·3

The gearing is wonderfully quiet. The little noise it makes is rendered entirely

unnoticeable by the noise of the carbon brushes on the commutators, so that it is obvious that it cannot be very great. No sign of wear was evident after the locomotive had run 5,000 km. As far as accessibility of the motors and accessories is concerned, the design could not have been improved upon. It is possible to observe the working of all the pieces of apparatus—which has proved most useful

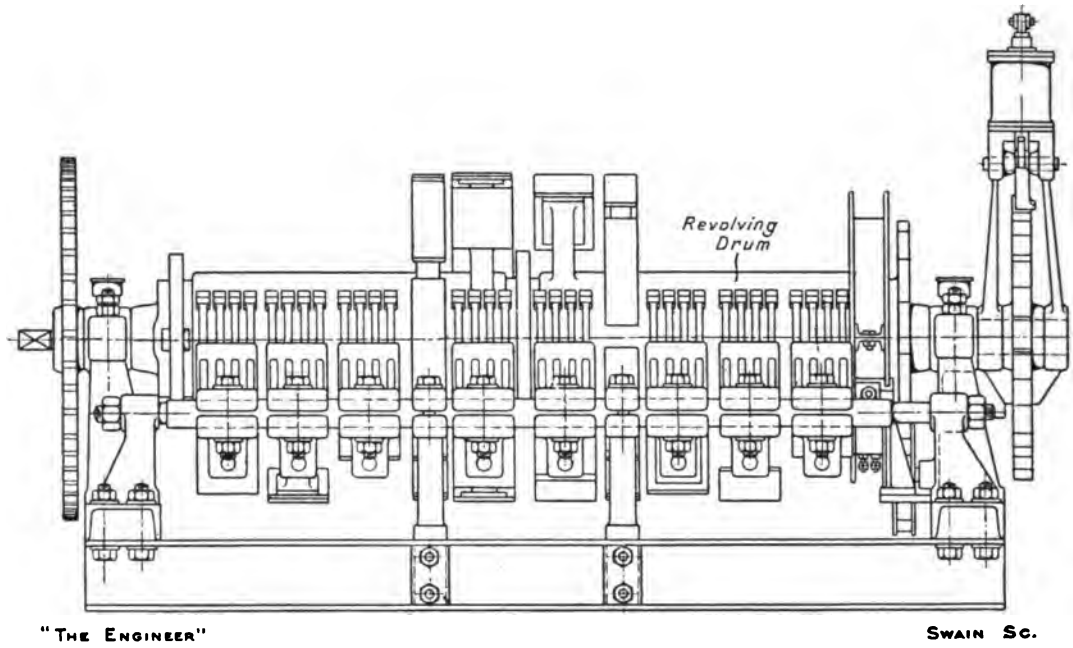

FIG. 260.—Control Gear.

to the drivers. The following figures were arrived at in a trial run between Spiez and Frutigen :—

Length of journey	13·0 km.
Difference of level climbed through	150·0 m.
Weight of the train	346·0 tons*
Total ton-kms.	4500·0
Theoretical work at the drawbar	220·0 kw. hours
,, watt hours ÷ ton-km.	49·0
Kw. hours as measured	264·0
Watt hours ÷ ton-km. as measured	59·0
Efficiency	·835·0 per cent.

A record of a run by a train made on May 9th, 1911, is shown in Fig. 255.

The motors run from no load to full load entirely sparkless, just as do well-designed continuous current machines, though at full load a current of 2,000 amperes at 420 volts is passing. It is only when starting with full load up an incline and when the current at first rises to 2,500 amperes that there is a slight momentary and inoffensive sparking. Fig. 256 shows the measurements taken with this locomotive starting up an incline of 15·5 per 1,000 with a load of 370 tons. Various sections are shown in Figs. 257, 258 and 259.

One important and interesting feature in connection with the new locomotives for the Lötschberg-Simplon line is to be found in the controlling gear. The terminal pressure of the motors of the new locomotives is about 400 volts, and at full load the

* This is only about 50 per cent. of the normal load.

current is about 3,000 amperes, and if the voltage is varied in twelve stages, each stage would give rise to an increase of about 100 kilovolt-amperes. In the locomotives previously described in this book, the control has been carried out by three different methods, viz., by contactors, by an induction regulator and by brush shifting. Of course, the use of a large number of contactors is to be avoided if possible, and one method which simplifies matters in this direction is to employ an induction regulator. After experimenting with induction regulators, however, the Oerlikon Company has decided not to use them on its locomotives, on account of the fact that they increase the cost and weight and lower the power factor. With the object of dispensing with the contactors and induction regulators, therefore, the Oerlikon Company has designed special controllers for direct-control, and these have been built for capacities

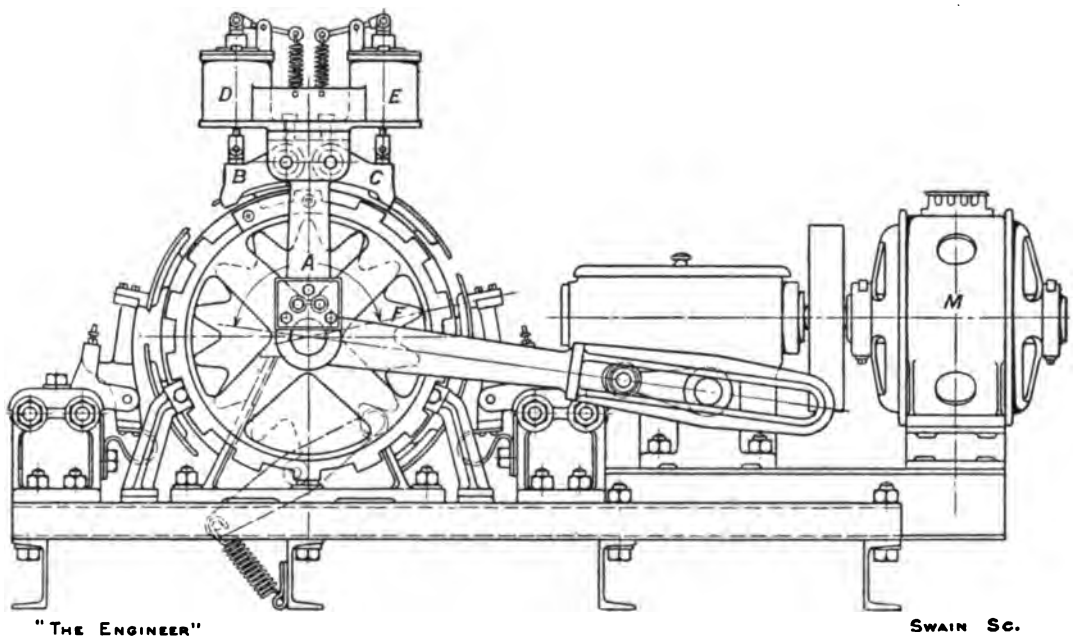

FIG. 261.—Control Gear.

up to 1,000 and 1,250 h.p. These controllers are now used on the No. 121 engine just described as well as on all the new locomotives.

As stated above, the Lötschberg locomotives are provided with two transformers, one for each motor. In order to control the voltage of these transformers, therefore, two controllers combined together are now employed, and the contact fingers of these are connected to the tappings of the transformers, so that the secondary pressures can be changed. Each transformer is fitted with an independent controller fixed immediately above the transformer, so that the windings are directly connected with the contact fingers. Two drawings of one of these controlling switches, suitable for dealing with currents up to 3,000 amperes, are shown in Figs. 260 and 261. It will be gathered that the controller is of the revolving drum type, and that the main drums are actuated in similar manner to a Thury regulator. The motor M on the right of Fig. 261 imparts a rocking motion to the member A, which in turn rocks the member carrying the pawls B C. The small electromagnets D E, which are energised with continuous current from a battery, can lift the pawls out of engagement with the notched wheel F. Thus when the pawl B engages with the wheel F the

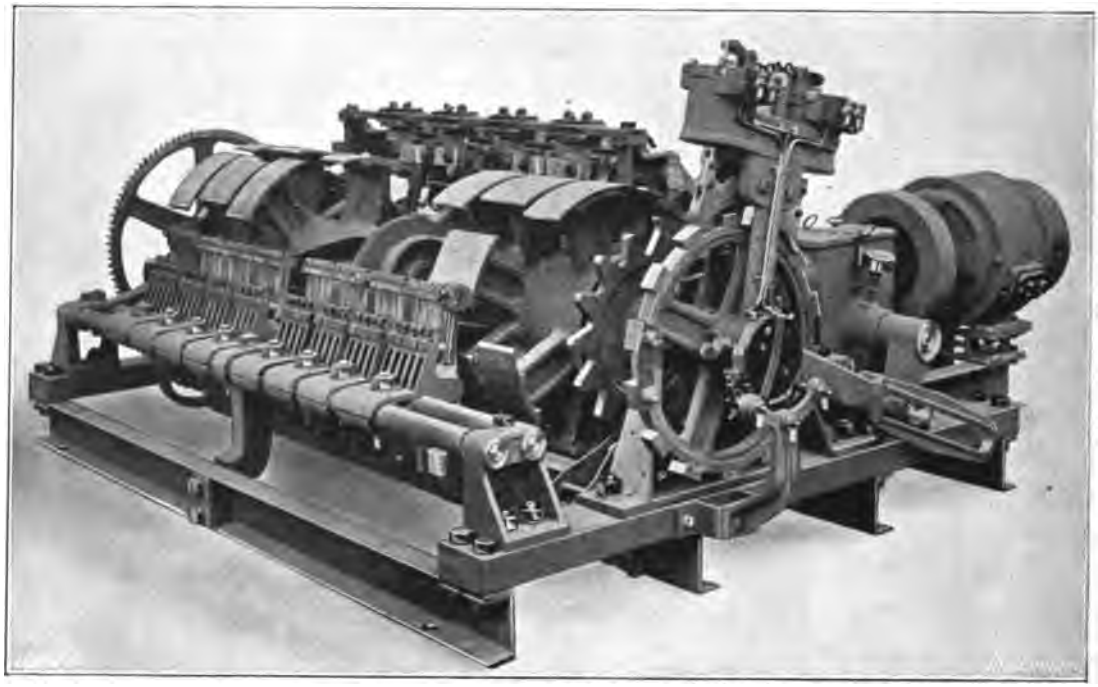

FIG. 262.—Controller.

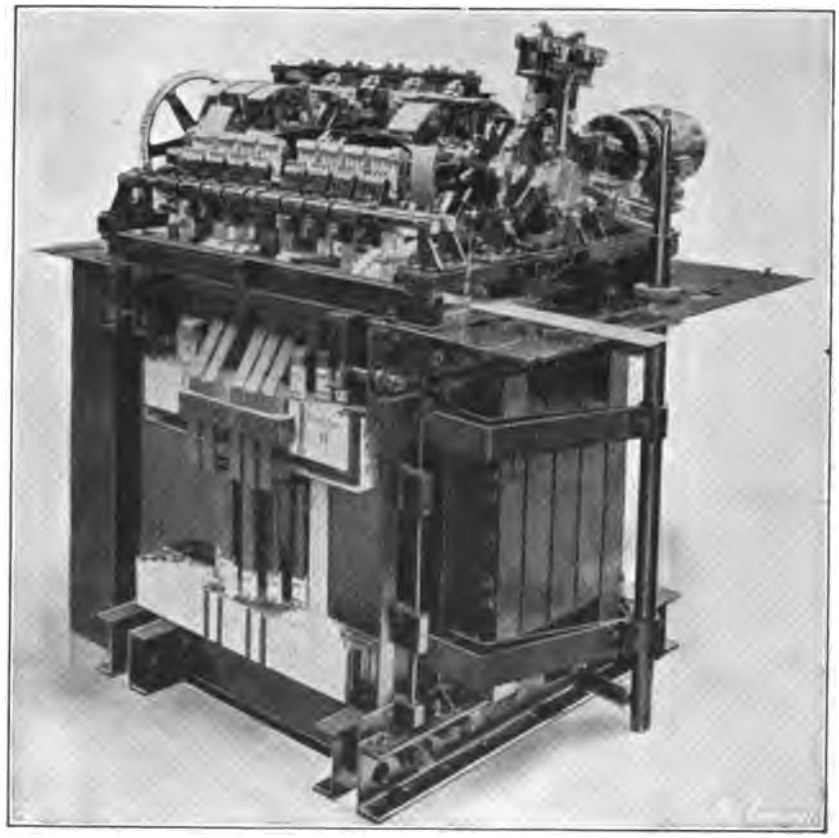

FIG. 263.—Transformer with Controller on Top.

FIG. 264.—2,500 h.p. Locomotive.

latter will turn in a counter clockwise direction, whilst when the pawl C is allowed to actuate the wheel F the main controller drums turn in the opposite direction. The length of the controller is 1·6 m., the width 1·5 m., and the depth ·83 m. Altogether the controller weighs about 1 ton. It will be understood that with this design of control gear the switches in the driver's cabin simply energise the electromagnets D and E when the revolving drum is caused to turn in either direction in the manner described. A view of an actual controller of this type is shown in Fig. 262, and Fig. 263 shows a controller mounted on top of a transformer. With the aid of two of these controllers it is possible to connect both motors in series or parallel, as circumstances demand, or if desired the transformers can be dealt with in a similar manner. It is also possible to control the two motors by series and parallel connections from a single transformer and controller.

In the event of anything happening to the electromagnetic gear these controllers can be directly operated by hand. There are two cylinders, one of which is connected to the transformer tappings; the other is provided with magnetic blow-out gear and effects the making and breaking of one or the other of the circuits of the auto-transformer. Thus it will be seen that instead of using about a dozen separate contactor switches, the Oerlikon Company has now adopted a single switch unit for each motor, and the controlling equipment has consequently been considerably simplified.

A view of one of the new 2,500 h.p. locomotives is given in Fig. 264, and for a full description the reader should refer to *The Engineer* for November 21st and December 5th, 1913. Here it must suffice to say that in this type of engine both the motors are placed in the centre of the body and the transformers near the end, whilst, as the drawing, Fig. 240, shows, the transformers of Locomotive No. 121 are in the centre and the motors at the ends. The positions of the jack shafts, Fig. 264, indicate that the motors are at the centre of the engine. Fig. 263 shows one of the transformers and controllers belonging to the engine shown in Fig. 264.

As this illustration shows, the locomotive is of the 2-10-2 type, with five coupled axles and two running axles. The table below gives the principal data :—

Total length measured over buffers	16·000 m.
,, of wheel base	11·340 m.
Fixed wheel base	4·500 m.
Diameter of driving wheel	1,350 mm.
,, runner wheel	850 mm.
,, crank circle	600 mm.
Ratio of tooth gear	1 : 2·23
Weight of the mechanical part	47·3 tons
,, ,, electrical part	59 tons
Total weight	107 tons
Weight on driving wheels	78·2 tons
Maximum weight on any axle	16·6 tons
1½ hours capacity	2,500 h p.
Tractive force at the wheels at 1½ hourly capacity	13,500 kilos.
Speed at 1½ hourly rating	50 km. per hour

The engine is capable of developing at normal speed a draw-bar pull of 10,000 kilos., and can draw a train weighing 310 tons up a gradient of 2·7 per cent. The tractive force at the wheel circumference is 13,500 kilos., and the maximum speed is 75 km. per hour. All the new engines are capable of exerting at starting a draw-bar pull 30 per cent. in excess of that mentioned. The body is divided into three compartments—the motor compartment and two drivers' cabins.

CHAPTER VII

THE ROTTERDAM-SCHEVENINGEN RAILWAY

A SINGLE-PHASE railway connecting Rotterdam and Scheveningen, with a branch line to The Hague, was put into operation on October 1st, 1908. It was originally intended that the line should be worked with continuous current at 850 volts, but whilst the railway was under construction certain unforeseen difficulties a ose, and the work took much longer to execute than was anticipated In the meantime the advantages of the single-phase system were recognised, with the result that the original scheme was abandoned and the newer system of electric traction introduced.

From the station at Rotterdam the railway extends in a northerly direction and practically in a straight line for a distance of twelve and a half miles. It then divides and one part of the line goes north to Scheveningen and the other west to The Hague. The distance from Rotterdam to The Hague is fifteen miles, from Rotterdam to Scheveningen nineteen miles, and from The Hague to Scheveningen seven and a half miles.

The generating sets were designed with the object of working the railway with continuous current, and they were nearly finished before the use of the single-phase system was decided upon. Thus, in accordance with the usual practice, they were built as three-phase machines. But in view of the decision to discard the original scheme, various alterations in the generators were considered necessary. To render them suitable for the new conditions the stator windings were divided into two parts and connected in parallel. This reduced the original working pressure of 10,000 volts to 5,000 volts with a corresponding increase in the current output. Moreover, the three-phase current derived from the alternators is changed into two-phase current by means of transformers connected in accordance with the scheme devised by Scott. The pressure of the two-phase system is 10,000 volts. Eight transformers are used for the phase transformation, two of which have a capacity of 12,000 kilovolt-amperes, and the others an output of 600 kilovolt-amperes. It will be gathered, therefore, that this change in the original scheme has introduced special arrangements which would not have been necessary had the single-phase system been chosen in the first instance.

The generating station is situated at Leidschendam, which is about eleven miles from Rotterdam. It is in close proximity to the railway and on the banks of the Leyden Canal, thus enabling coal, etc., to be brought to the station by water. The station contains four generating sets Two of the alternators are coupled to reciprocating engines and generate three-phase current at 5,000 volts and at a periodicity of 25 cycles per second, the capacity of each generator being 850 kilovolt-amperes. The other two alternators, which have a capacity of 2,000 kilovolt-amperes, are driven by steam turbines of the Zoelly type. Two converters have also been put down in the power-house, and they are used for exciting the main generators for lighting the station and for driving various small motors. Each converter works in conjunction with oil-cooled transformers, which change the two-phase current at 10,000 volts into three-phase current at 500 volts. A storage battery having a capacity of 1,050 ampere-hours works in parallel with these converters.

All the electrical equipment for this railway was supplied by Siemens-Schuckert.

The line is divided into two parts, one of which is fed with one phase of the generating system and the other with the remaining phase. Referring to the diagram, Fig. 265, which shows the feeder and sectioning arrangements, the separation of the two phases occurs at a point a little over half a mile north of the Pynacker Station. The object of fixing upon this point for dividing the phases was to enable the load on each phase to be the same under normal working conditions. It will, of course, be understood that at this point there is a break in the overhead conductors, and that the wires are divided by a dead section, this being about 4 yds. long. The northern section of the line is fed at a point eight miles from Rotterdam, and, as will be gathered from the diagram, Fig. 265, this point is quite close to the power station. The feeders consist of two bare wires. Feeders also run from the power-house to the southern section of the railway, and as in the case of the other feeders, they are supported on masts placed between the two lines of rails. The feeding points are shown on the diagram, Fig. 265, at X and Y, *aa* being the Rotterdam

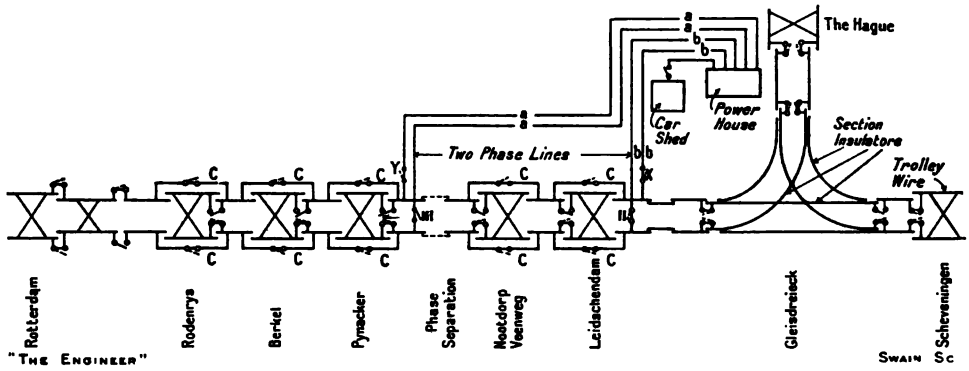

FIG. 265.—Feeder and Sectioning Arrangements, Rotterdam-The Hague-Scheveningen Line.

feeder and *bb* the Scheveningen feeder, and from what has been said it will be understood that these feeders *aa* and *bb* constitute two distinct phases.

The overhead construction used on this railway is of the Siemens type as employed on the electrified section of the Midland Railway. The Siemens system of catenary trolley wire suspension for electric railways provides an elastic support for the trolley wire, and maintains it almost perfectly parallel to the rails, thus enabling the current to be collected without difficulty even at very high speeds. The insulators for the catenary cable are fixed on brackets or cross girders attached to the poles. An auxiliary wire is suspended under the catenary cable by means of vertical droppers spaced at uniform distances along it. In the middle point of the span where the auxiliary wire is close beneath the catenary cable they are connected by special clips. The droppers are attached to the catenary cable and to the auxiliary wire by means of clips. The trolley wire is hung under the auxiliary wire by means of loop-shaped clips which allow the trolley wire to rise. The trolley wire is made of copper and usually has a figure 8 section.

To prevent the trolley wire swinging sideways a tie is provided at each pole or bracket. This is so designed that the trolley wire can rise under the action of the upward force of the bow collector. To allow for changes in length of the wires due to changes of temperature tightening arrangements are erected at regular intervals. The trolley wire is automatically tightened by means of weights moving up and down the poles, and connected to the trolley wire by means of chains passing over pulleys.

Several examples of the overhead construction are shown in Figs. 266—269,

including the phase-separating section at Pynacker, a mast with double bracket arm on the open track, the method of fixing masts on the Rotterdam viaduct, and the

FIG. 266.—Phase Separating Section.

overhead equipment at Rotterdam. A view of the automatic trolley wire tighteners as used with the Siemens catenary system is also shown in Fig. 270. For the purpose

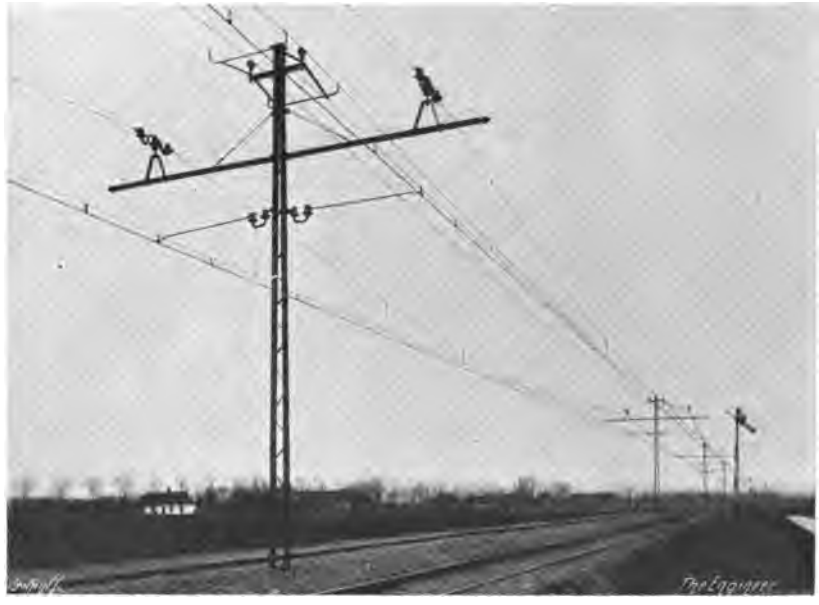

FIG. 267.—Double Bracket Arms on Open Line.

of testing the insulation of the line at a pressure ranging from 25,000 to 30,000 volts an accumulator locomotive is used which carries a converter.

Considerable difficulty was experienced in connection with the construction of the railway owing to the marshy nature of the soil, and this was mainly responsible

FIG. 268.—Overhead Equipment on Rotterdam Viaduct.

for the delay previously referred to. The majority of the masts were fixed in concrete, which was run into special cast iron boxes sunk in the earth, this construction being

FIG. 269.—Overhead Equipment on Rotterdam Viaduct.

necessary owing to the nature of the soil. But in view of the fact that a viaduct in the neighbourhood of Rotterdam is built of reinforced concrete, large holes which

would accommodate the boxes could not be sunk, and in consequence the masts had to be erected by fixing them to the viaduct uprights in the manner shown in Fig. 268.

The automatic trolley wire tighteners, as shown in Fig. 270, are erected every 1,000 m., and at these points the wires are stretched by a weight and are continually under a tension of about ½ ton. Since it is necessary for the trolley wire and suspension wire to be divided up into sections, it is obviously convenient to arrange for the provision of a section insulator at these tightening posts. The two ends of the trolley wire are not directly connected together, but are joined through a horn switch, which is fixed on a special post and worked from below by means of a rod.

A section insulator is provided both in front and behind the stations. There are also two cross wires, thus rendering it possible to make the trolley wires dead

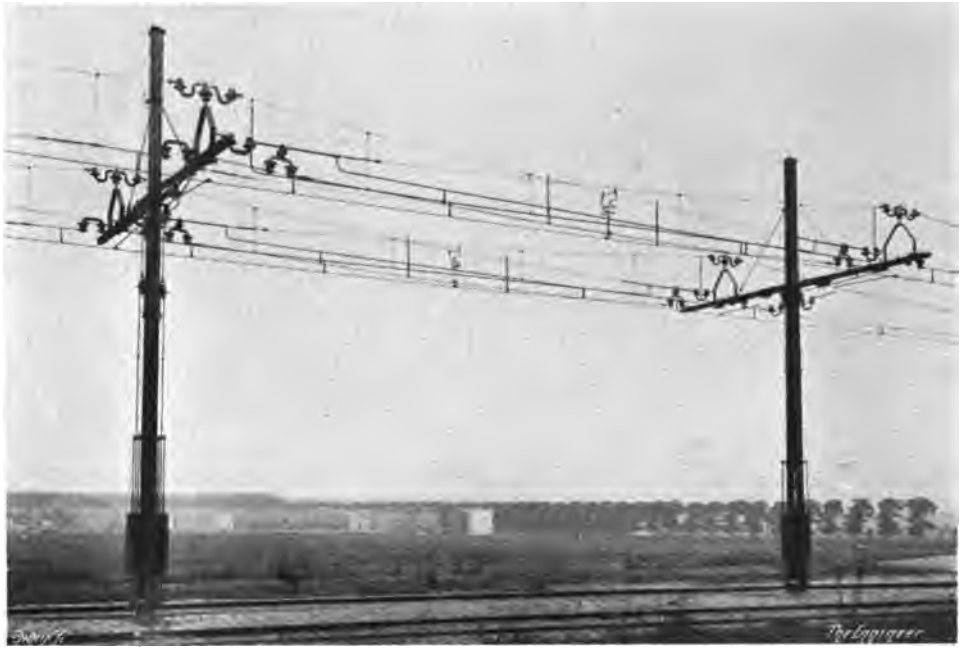

FIG. 270.—Automatic Wire Tighteners.

at the station without affecting the working of the remainder of the line, whilst at the same time each wire can be cut out between any two stations. At the junction between Leidschendam and The Hague the conductors pass underneath a bridge which is only 16 ft. above the rails and the clearance between the bridge and wires is only 10 in.

Turning now to the rolling stock, when the railway was first opened there were nineteen motor coaches and nine trailers. The coaches have central corridors with the seats on each side and separated from each other by a low partition. There are two types of motor coaches, one for second and third class passengers and the other for second-class passengers only. The first-mentioned type is fitted with four sliding doors which divide the compartments into two parts for smokers and non-smokers. These coaches have twenty-four seats for second-class passengers and forty-nine seats for third-class passengers. There is also sufficient space to accommodate about fourteen passengers standing. The driver's compartment contains the usual controller

and switch for working the brakes, and a lever for raising and lowering the collector and valves for working the whistle and sanding equipment. There is also a switch for the motor which drives the blower for cooling the motors. Only one bogie of each motor coach is fitted with driving motors. The other carries a 5 h.p. alternating-current motor working at a pressure of 110 volts, which drives the air pump for supplying compressed air to the brakes and for raising and lowering the current collector, and also for the sanding apparatus and whistle.

The maximum pressure at the low-tension side of the transformer is 300 volts. In accordance with the usual practice on single-phase railways, all the high-tension parts are placed in a special chamber and all the accessible parts are properly earthed. A lightning arrester is fixed on the roof of the coach to protect the electrical apparatus against atmospheric discharges. The trailer coaches are each capable of seating eighty-

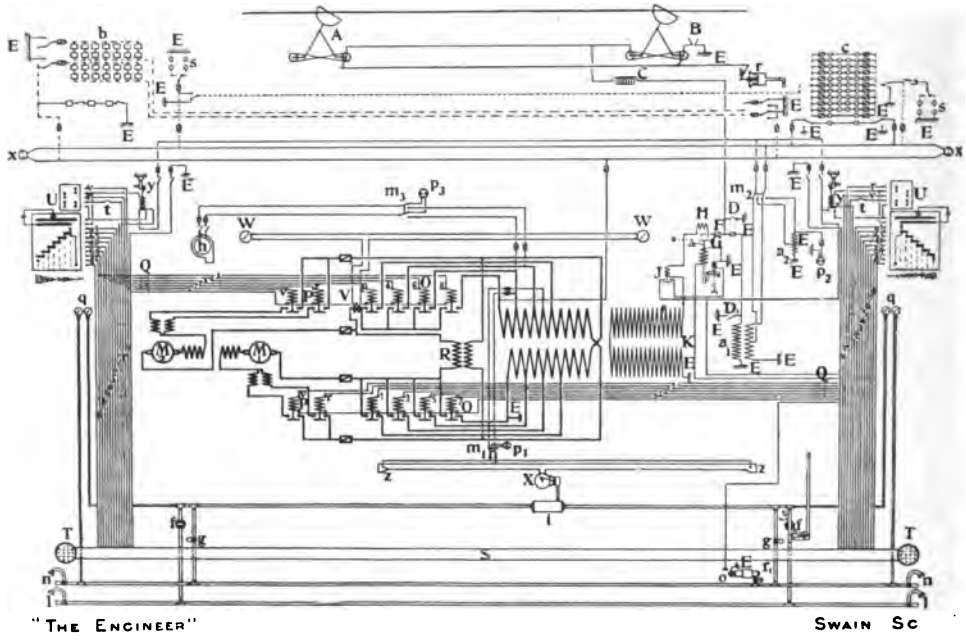

FIG. 271.—Motor Coach Connections.

eight passengers, and there is room to accommodate twenty other passengers standing. Each motor coach is propelled with two Siemens series motors having a capacity of 180 h.p. when running at a speed of 750 revolutions per minute.

Contactor control is adopted on all the motor coaches, and the contactors are worked with alternating-current magnets. The method of controlling the motor coaches will be understood by reference to the diagram of connections, Fig. 271. A is the high-tension current collector, B the lightning arrester, C the choking coil, D the earthing switch, D_1 the earthing switch for the lighting and auxiliary transformer, F the high-tension fuse, G the high-tension switch, H the high-tension series resistance, J the high-tension circuit breaker, K the main transformer, M_1 and M_2 the main motors, O the contactors, Q contactor control circuit switch, R a special balancing transformer, the function of which will be described later, S the controller cables, T the connecting plugs for the controller cables, U the master controller, W the ammeter, X the air pump, a_1 the lighting transformer, a_2 the testing transformer, b the heating elements, c lamps, f the lever for raising and lowering the current collectors, g the lever

for operating the brake, h the motor for working the blower, i the main air container, l the pipe coupling for the collector apparatus, m_1 the switch for the air pump motor, m_2 the switch for the lighting and controller circuit, m_3 the switch for the blower motor, n the pipe coupling for the air brake, p_1 the plug for the pump motor circuit, p_2 the plug for the lighting and controller circuit, p_3 the plug for the blower motor, r the air cylinder for the current collector, and s the signal lamps.

Of course, the contactors are operated with the aid of a master controller, which only deals with the small currents necessary for actuating the contactors; the pressure used on the operating circuit is 150 volts. This control current is derived from the lighting transformer. The secondary winding of the main transformer is divided into two parts, which are so connected with the two motors that the two

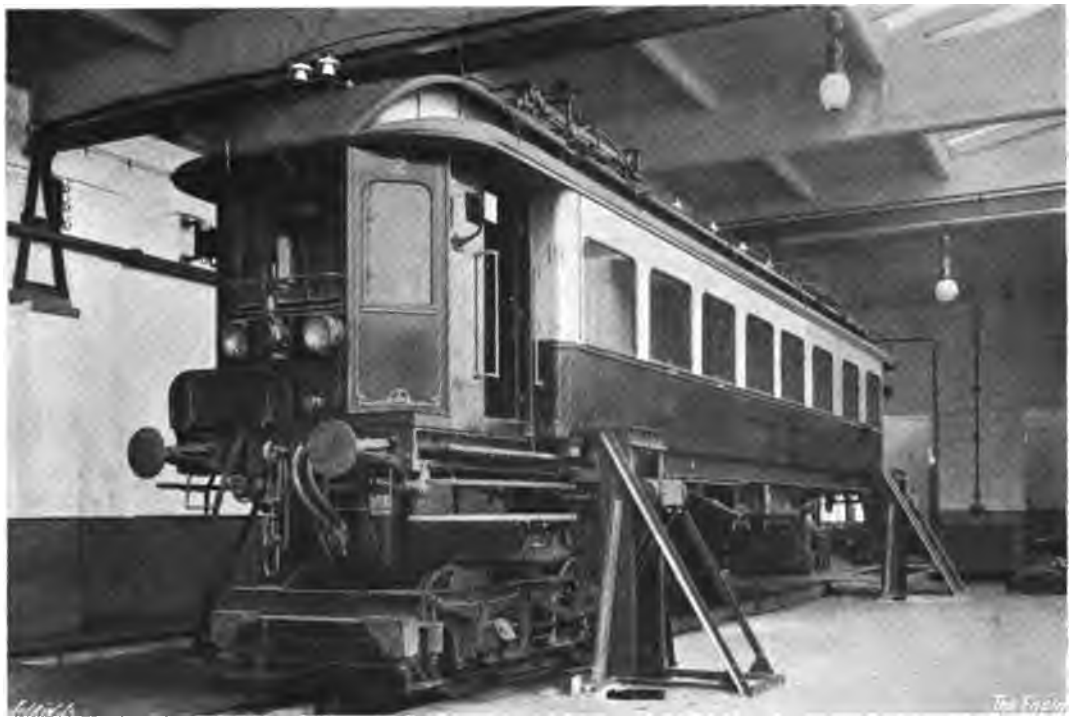

FIG. 272. Motor Coach in the Repair Shop.

halves of the winding constitute a single series circuit. These connections will be understood from a careful examination of the diagram. Each motor takes the same current, but the sum of the voltages in the two transformer windings is equally divided between the two motors. The four pressures obtainable from one winding of the transformer are 116, 175, 244, and 314, whilst the voltages which are derived from the other winding are 151, 210, 280, and 361 volts.

When the controller handle is placed in the first position, the sum of the two voltages 116 and 151 is impressed on the two motors. The sum of 116 and 151 is 267, so that the pressure at the terminals of each motor is 133·5 volts. It is worthy of note that with this special system of control, in spite of the series connections, there is never a higher voltage between any two points of the circuit than would exist with ordinary parallel working. A transformer with a ratio of 1 : 1 is also connected in the motor circuit in the manner indicated in the diagram. The object of this is

to enable one motor to be cut out of circuit in the case of damage, and also to prevent the circuit being completely broken by the opening of a contactor.

Lastly, a word or two may be said with respect to the coach sheds. They have been built quite close to the power-house and in the vicinity of the Leidschendam station. They are capable of accommodating forty-eight coaches, and in order to avoid possibilities of fire they are divided by partitions into a number of compartments or shops. Each shed has twelve tracks, and six are provided with inspection pits throughout the whole of their length, thus enabling repairs to be carried out with a minimum amount of trouble.

Wall plugs are fitted in the pits so that hand lamps can be connected for inspection purposes. These plugs also enable current to be obtained for testing the lighting and other circuits of the coaches. A compressed air plant for cleaning the coaches has also been put into use. The repair shops which are adjacent to the coach sheds contain various machine tools, which are worked with continuous-current motors. A jacking arrangement has also been erected for lifting the coach bodies off the bogies, as shown in Fig. 272. No high-tension wires are used in the sheds, but a shunting track has been put down which has its own special overhead equipment, so that running tests may be carried out when desired. All shunting work, however, is carried out by two accumulator locomotives, each of which is worked with a 120-cell battery having a capacity of 185 ampere-hours, and fitted with two 31 h.p. motors working at 220 volts.

CHAPTER VIII

THE THAMSHAVN-LOKKEN RAILWAY

THE first single-phase railway put into operation in Norway was the Thamshavn Lokken line, which was built for the purpose of carrying goods and ore and for providing travelling facilities for residents and tourists in the surrounding country. The line runs inland for a distance of about seventeen miles, and borders the river Orkla as far as Svorkmo, from which point it proceeds to Lokken, where some of the principal ore mines in Norway are situated. At the other end of the line, namely, at Thamshavn,

FIG. 273.—Thamshavn Terminus.

there is a large timber works where the picturesque wooden houses which form such a characteristic feature of Norwegian scenery, are made. In a valley at Skjenald Fossen to the west of Thamshavn a water power station has been erected which provides current for working the line and also for lighting in Thamshavn and the villages in the neighbourhood of the railway. Power is also taken from this station for working the mining machinery at Lokken.

Since three-phase current is generated in the power house, it became necessary to build a sub-station at Thamshavn, where the pressure is reduced from 15,000 volts to 6,600 volts and the three phase current changed into single-phase 25-cycle current for use on the railway. This sub-station adjoins the workshops at Thamshavn, and

consists of a substantial brick building with concrete foundations. The transformation from three-phase current to single-phase current is carried out by means of motor generator sets, each consisting of a slip-ring induction motor coupled to a single-phase alternator. The voltage is lowered by means of oil-insulated transformers.

The line, which has a gauge of 1 m., is fairly straight from Thamshavn to Svorkmo, the minimum curve radius being 250 m. It then rises rapidly all the way to Lokken, and the gradients on this part of the railway amount to as much as 4 per cent. A view of Thamshavn terminus on Orkedals Fjord, showing the sub-station running shed, and workshop, is given in Fig. 273 ; and a view of the Solbu station which is a typical example of a wayside station on the railway, in Fig. 274. The illustrations, Figs. 275 and 276, show a passenger train at Thamshavn station and an embankment

FIG. 274.—Solbu: A Typical Wayside Station.

near Svorkmo. At each station there is a stationmaster's office, a waiting room, lavatories, and a goods warehouse. Altogether there are seven stations. It will be gathered that the buildings are of substantial log construction, and have turf-covered roofs, giving a picturesque appearance. The buildings and platforms are lighted with incandescent lamps fed from a small transformer, which is connected to the trolley circuit.

The overhead equipment is constructed in accordance with the designs of the Westinghouse Company. A hard-drawn copper wire having a section of 65 sq. mm. is suspended from a steel cable, which is carried on insulators. The latter are mounted on steel brackets having a T section, and these are carried on wooden poles and supported by tie rods. A good idea of the design of the overhead construction will be gathered from the illustrations, Figs. 277, 278, and 279. The spans between the poles vary from a maximum of 150 ft. on straight lengths of the line to 68 ft. on curves,

FIG. 275.—Passenger Train at Thamshavn Station.

FIG. 276.—An Embankment near Svorkmo.

and the poles are so placed that under no circumstances is the wire more than 9 in. from the centre of the line.

A double galvanised steel wire, made up of seven strands, supports the copper trolley wire by means of stiff vertical hangers. These latter have two forged clamps at their lower ends, which embrace the upper half of the trolley wire, and are so constructed that when once erected they are locked in position, although they can easily be unfastened when desired. The line is divided into six sections by means of section insulators, as shown in Fig. 278, so that it is possible to cut out any section without interfering with the traffic on the remainder of the railway. Under normal conditions each section insulator is short-circuited by a horn type switch, which can be opened and closed by means of a bamboo pole and hook. When the railway was first opened

FIG. 277.— Overhead Construction on Curves.

FIG. 278.—Section Insulator and Switch.

there was no long feeder, as the trolley wire had a sufficiently large section for the traffic conditions. The normal height of the trolley wire above the rail is 5·5 m , but this is reduced to 4·3 m. at the bridges—as shown in Fig. 279.

Turning now to the rolling stock, electric locomotives are used for hauling the goods and passenger trains. Each weighs 20 tons and carries four motors on two bogies. The bodies are made of mild steel, and are provided with buffer gear and Westinghouse non-automatic air brakes. One of the locomotives is shown in Fig. 280. The high-tension current is collected by a pantograph bow collector, mounted on the roof, and passes through an insulated cable to an automatic circuit breaker, and then to the transformer, which is suspended inside the cab. This arrangement reduces the length of the high-tension cable to a minimum, the total length being only about 10 ft. The whole of the high-tension apparatus is enclosed by a metal screen which is earthed. One of the most notable features of the locomotives is the great simplicity

of the electrical connections. From the collector the current passes through the winding of an auto-transformer, one end of which is connected to earth.

Several tappings are brought out from the low-tension end of the transformer and are connected to the fixed contacts of the controllers at each end of the locomotive. Each notch on the controllers connects two successive tappings to a preventive coil, the function of which is to prevent the motor circuit being broken when moving the controller handle from one position to another. The centre point on this coil is connected to the motors, which latter are connected in two groups, each group consisting of two motors in series. A cut-out is fitted in the base of each controller, so that either group of motors may be cut out when desired without interfering with the other pair. An electrically driven air compressor fitted with an automatic governor supplies compressed air to a main reservoir. The compressed air is used for the brakes and for raising and lowering the pantograph bow. In order to render it possible to operate the bow in the event of failure of the air compressor a hand pump is provided. A whistle is placed at each end of the locomotive, and is controlled by a push valve within easy reach of the driver.

The motors are of the Westinghouse single-phase series compensated type, and have an hourly rating of 40 h.p. The power is transmitted from the motor shafts to the driving wheels through gearing, the pinions having fourteen teeth and the gear wheels seventy-six teeth, whilst the diameter of the driving wheels is 33 in. Each locomotive is capable of exerting a tractive effort of 6,500 lb. at ten miles per hour and a maximum tractive effort at starting of 8,000 lb.

FIG. 279.—Overhead Construction at a Bridge.

For the use of the directors of the company a saloon motor coach has been built. This coach, which is shown in Fig. 281, is 39 ft. 4 in. over headstocks and 8 ft. 6 in. wide at the waist rail, and weighs 22·8 tons. The interior is divided into a vestibule and driver's compartment at each end and two saloon compartments, separated from each other by a short passage. One compartment is fitted with a writing table and swinging armchair, and the other is furnished with cross seats and a central gangway. The body is carried on a substantial underframe, which is supported by two wing bolster trucks. One of these is equipped with two 40-h.p. motors similar to those used for propelling the locomotives.

The railway was formally opened on July 10th, 1908, and public traffic was commenced on July 15th. The passenger traffic has exceeded all expectations, and it is frequently necessary to run trains in duplicate on Sundays and holidays. The main contract for the whole of the work was entrusted to the British Westinghouse Company, through its agents in Norway, the Elektrick Bureau of Christiania, and the following firms acted as sub-contractors :—For the locomotive

bodies, W. G. Bagnall, Limited, Stafford ; and for the saloon motor coach, the United Electric Car Company, Limited, of Preston. The remainder of the rolling stock was supplied by the Skabo Railway Carriage Works, of Christiania.

FIG. 280.– 20-Ton Electric Locomotive.

FIG. 281.—Saloon Motor Coach.

THE RJUKAN RAILWAY

THE Rjukan Railway, in the South of Norway, has recently been electrified on the single-phase system by the A.E.G. Company. It is composed of two sections, which are separated by the Tinn Lake. The northern section, which extends from Saaheim to the Tinn Lake, is 16 km. long. The southern section is about 30 km. long and extends from Tinnoset to Notodden, along the Hitterdals Lake. A ferry across the Tinn Lake gives a connection between the two sections. The railway is mainly intended for the transport of saltpetre, which is manufactured in Saaheim and Notodden. A portion of the line passes through a forest, this having necessitated the overhead conductors being placed very near to the telephone wires. Trains having a trailing weight of 290 tons are at present being drawn on the section from Notodden to Lilleherred by two locomotives. At present there are five locomotives, two being of the four-axle type and three of the two-axle type. The former, which have two bogie trucks, are fitted with four alternating-current motors, each rated at 125 h.p. for one hour. The weight is approximately 46 tons. The two-axle locomotives have two motors of the same size and weigh about 23 tons. A line pressure of 10,000 volts has been adopted. The periodicity is 15 cycles per second.

The overhead equipment is of the single catenary type, the distance between poles being about 60 m. On some sections bracket suspension is used, whilst on others cross suspension is employed. There is a separate converter station for each section of the line, wherein three-phase current is converted into single-phase current at a pressure of from 10,000 to 11,000 volts for use on the railway. The converter station at Vestfjorddals contains two converters, each consisting of a three-phase induction motor driving a single-phase generator having an output of 400 kilovolt-amperes, which supplies current to the line. This converter station receives its energy from the Rjukan power station, about 5 km. distant. The southern section is fed from the Svelgfos converter station, which is situated in the same building as the power station. The converting plant in this instance consists of three converters similar to those described.

A difficulty that arose in connection with the electrification of this line was that when the overhead wires were energised and the locomotives set to work disturbances were set up in the telephone circuits. The telephone wires are supported on ordinary insulators and are interlaced. Some of the telephone wires are only about 3 m. away from the track, and owing to the fact that this portion of the line passes through a forest it was not possible to place them in a more favourable position. Trouble was therefore anticipated, and the question of using a telephone cable with its sheath earthed was considered, but as the manufacturers were unwilling to guarantee the life of the lead sheath under the conditions existing, this idea was abandoned. The most troublesome causes of disturbance are the pressure drop in the earth return and electromagnetic and electrostatic induction. To eliminate the first trouble all single circuits near the high-tension conductors were provided with a metallic return. But in spite of this, when the locomotives were put into service the ringing apparatus was found to be very sensitive to the 15-cycle current. In order to eliminate

electrostatic charges discharge coils having a resistance of 750 ohms have been connected across the double telephone wire at a distance of 2 km. apart, the middle point of these coils being earthed.

Notwithstanding the fact that the slots in the locomotive motors are skewed and that the specifications stated that generators were to be designed so that no harmonic should be more than 4 per cent. of the fundamental, very serious troubles in connection with the telephones were experienced. The starting of the locomotives produced noises in the receivers, and this occurred to a marked extent on the circuits composed of double lines. The noise, however, was most pronounced when the locomotives were in motion, and it was found to be independent of the speed of the engines or the strength of the commutating field. The annoyance became much worse in wet weather, and in some cases it was impossible to use the telephones. Ultimately investigations were undertaken by Dr. F. Marguerre, and particulars of the experimental work which he carried out were recently given in the *Elektrotechnische Zeitschrift*. The phenomenon was investigated by means of the oscillograph. Dr. Marguerre found that the trouble was caused by tooth pulsations in the generators. The harmonic in the pressure wave which was mainly responsible for the trouble was found to have a frequency of 568 cycles, and when the machine was dealing with an inductive load the amplitude increased up to 17 per cent. of the fundamental wave. An inductive load greatly intensified the trouble.

The trouble was finally overcome, or at any rate considerably diminished, by connecting a resonance circuit across the terminals of the generators. The values of the capacity and self-induction of this circuit were so chosen that a short-circuit was produced for a frequency of 560 cycles, so that no pressure at this frequency can exist on the overhead line. Experiments indicated that a capacity of ·2 microfarad and an inductance of ·4 henry gave the best results. The current in the resonance circuit does not exceed ·36 ampere, indicating that the alternators have high reactance, a condition that is necessary to enable the high frequency pressure to be suppressed.

CHAPTER IX

THE SWEDISH STATE RAILWAYS

In Sweden the electrification of railways is of great importance, for the country contains little coal. Coalfields exist only at a few places in the extreme south, and nearly the whole supply has to be imported. The State Railway authorities purchase approximately £400,000 worth of English coal per annum, and the privately-owned railways about the same amount.

But Sweden is rich in waterfalls, and with a view to utilising these the State began, as far back as 1902, to consider the electrification of its railways, and experiments were carried out during 1905—1907 on the lines between Tomteboda and Värtan and Stockholm and Järfva, at pressures up to 20,000 volts.

The results of these experiments led the Government to conclude that a single-phase 15-cycle system would be most suitable for the State Railways.

The first lines considered were those with heavy and regular traffic, and not far from a waterfall, and it was finally decided to electrify the Kiruna-Riksgränsen line, in the extreme north, a line used chiefly for transporting ore.

Kiruna is celebrated for its iron ore deposits, which are worked from the surface. Ore is delivered into three-axle, self-discharging waggons, weighing 11 tons empty and 35 tons full, and is taken from Kiruna to the Norwegian port Narvik, via Abisko and the frontier town Riksgränsen. The Kiruna-Riksgränsen line is approximately eight miles long.

The State is under an agreement with the Kirunavaara-Luosavaara Co., the contractors for transporting the ore, to carry a constantly increasing weight of ore yearly. Thus, 1,660,000 tons were carried in 1908, and the State is compelled to transport 3,850,000 tons in 1918. With steam traction on the existing single track, this increase in traffic would be impossible, unless the line were duplicated in places and a number of steam locomotives of the heaviest type provided.

But the electrification of the line has made these alterations unnecessary, because the additional carrying capacity can be obtained by employing heavier trains running at higher speeds. The maximum safe length of train originally consisted of twenty-eight ore waggons, and one two-axle goods van; longer trains were found to throw too great a strain on the couplings. Oscillations are set up in slow running steam-driven trains on account of the tractive effort varying with the position of the piston, and the couplings break. Generally the trouble is confined to the couplings at the rear of the train.

With electric locomotives the length of the trains can be increased to forty ore waggons and one goods van, nearly 50 per cent. The speed was originally limited by the pounding action exerted by the oscillating masses of the engine on the couplings and rails, and could not safely exceed 25 miles per hour on the level. It fell to 7½ miles per hour when the trains were on the steepest gradient (about 1 per cent). With electric locomotives the maximum speed on the level is between 30 and 40 miles per hour, and can be maintained at 18 miles per hour up the inclines. It is calculated that the annual saving will amount to approximately £23,000 when

3,850,000 tons of ore are carried per annum. The absence of smoke is also of great advantage. Between Abisko and Björkliden the line has gradients up to 1 per cent. This maximum gradient is met with in a tunnel 1,200 yards long, and the steam engines had to develop full load on entering. The resulting volume of smoke was very troublesome.

All things considered, there can be no doubt that the report of the Railway Department to the Swedish Parliament, on April 4th, 1910, recommending the electrification of the Riksgränsen line and erection of a power station was entirely justified.

On May 20th, 1910, the Swedish Government adopted the report and voted approximately £1,200,000 for the scheme.

The execution of the entire scheme was placed in the hands of two firms, viz., Allmänna Svenska Elektriska Aktiebolaget Vesteras, and Siemens-Schuckert.

Although the line is primarily used for goods traffic, there are also a certain number of passenger and express trains. There is a fairly heavy tourist traffic in the summer, for the surrounding country is very picturesque. The line is the most northerly in the world; it lies within the Arctic circle. The line can be divided into two parts, *i.e.*, from Kiruna to Nuolja tunnel (four miles from Abisko), and from here to Riksgränsen. On the southern portion the snow plough and other devices in use in the north of Sweden are quite capable of keeping the line clear. But special measures have to be taken to deal with snow on the northern section. Snow galleries had to be built in and near cuttings, and a concrete tunnel to protect the line from avalanches at both ends of the Nuolja tunnel. Of the nineteen miles of the northern section, four and a half are in tunnels or snow galleries, and the remaining unprotected parts of the line have to be kept clear by rotary ploughs.

The railway has single track throughout except in stations. Its gauge is 4 ft. 8½ in.; the steepest gradient is 1 in 100, and the sharpest curve has a radius of 550 yards.

For generating electric energy it was decided to utilise the Porjus fall of the Luleälf river, seventy-five miles south of Kiruna, as if necessary its power can be increased very greatly later on. Sufficient energy for operating the railway and for present industrial purposes can be obtained with an average quantity of 5,300 gallons of water per second. But an output of five times this amount can be secured at comparatively small expense. The fall can give an average of 65,000 h.p. throughout the year. By regulating the river it is possible to increase the power of all the other falls lower down the Luleälf river, so that the State would have, on an average, 300,000 h.p. at its disposal. All the State Railways will eventually be electrified on the single-phase system.

The power house is built to accommodate for the present five 12,500 h.p. turbines. Three drive single-phase alternators generating current at 5,000 volts and a periodicity of fifteen periods per second for the railway. The other two turbines are coupled to three-phase alternators and supply current at twenty-five periods for various purposes.

The switch-house is built above ground, and the electrical connections to the machine room are led through a shaft in the rock. A railway to the Porjus power station is being built. This is a line thirty-three and a half miles long, connecting Porjus with Gellivare. Gellivare is one of the chief stations on the Lulea-Kiruna-Riksgränsen line, and is some sixty-two miles from Kiruna. The Porjus to Gellivare branch forms part of the projected main inland railway.

The 5,000-volt single-phase current is transformed up to 80,000 volts and is supplied to the sub-stations by overhead wires supported on iron poles. The feeders

follow the railway track from Porjus to Gellivare, and then branch off across ten miles of desolate and uninhabited country to the main line, which it follows to the various sub-stations. These are situated at Kiruna, Torneträsk, Abisko, and Vassijaure. Each sub-station contains transformers for reducing the pressure from 80,000 to 15,000 volts. The transformers are rated at 1,000 K.V.A. on continuous load, and 2,700 K.V.A. momentary.

The single catenary system of suspending the overhead wire has been adopted. The catenary wires are supported from wooden poles placed 33 yards apart, and the overhead wire is held by droppers. When passing through tunnels and snow galleries the wire is supported at shorter intervals than in the open. Automatic tightening gear for the overhead wire is also provided.

The locomotives are of special interest. Those for the ore trains weigh about 100 tons each, all the weight being utilised for adhesion. The engines are composed of two exactly similar parts joined together by a short coupling. Each part, which is complete in itself, is carried on three pairs of driving wheels, and is provided with a motor controlling apparatus and current-collecting gear. The motor is mounted in the body of the locomotive, and drives a jack-shaft by means of two connecting rods set at 90 degrees to one another. The jack-shaft is at the same height as the driving wheels, and is connected to them by coupling rods. The weight per axle is 16·7 tons. Each half-locomotive can be changed separately, so that the stock to be kept in reserve is reduced to a minimum.

The locomotives for the passenger and express trains are of the 2—B—2 type, and contain one motor similar in all respects to those in the goods locomotive. Since they only have to draw comparatively light trains (about 200 tons exclusive of engine), they have been designed with two pairs of driving wheels and two axle bogies fore and aft to ensure smooth running at high speeds. These locomotives weigh about 70 tons each.

Mineral trains consist of forty ore waggons, one luggage van and a locomotive at each end, the total weight when loaded being about 2,050 tons, and the maximum speed being about 31 miles per hour. A speed of about 19 miles per hour can be maintained up the steepest gradient (1 in 100) and round the sharpest curve (550 yards radius). In addition, the two locomotives are able to start the train on the steepest incline and on the sharpest curve, and are capable of developing an average effort of 686,400 lbs. The express locomotives are designed for a maximum speed of 62½ miles per hour. As stated at the beginning, as far back as 1905 the Royal Swedish State Railway authorities undertook some trials with main line trains on the Tomteboda line near Stockholm, one of the principal objects being to determine the safe limits of the working pressure. The rolling stock used consisted of two locomotives and two motor coaches, and the contractors associated with the work were the Siemens-Schuckert Company, the Allgemeine Elektrizitäts-Gesellschaft and the British Westinghouse Company. The locomotive shown in Fig. 282 was constructed by Siemens-Schuckert, and was used in connection with the above-mentioned trials. Fig. 283 shows the transformer belonging to the locomotive. The primary winding is arranged so that it can be connected for 5,000, 7,500, 10,000, 12,500, 15,000, 17,500 or 20,000 volts, whilst the secondary winding is provided with tappings, so that the pressure may be raised from 160 volts to 320 volts in steps of 20 volts. The capacity of the transformer is 300 kw. Two additional tappings are also provided, giving 120 and 240 volts, the first for the lighting and heating circuits of the locomotive and for working the auxiliary motors at low speed, and the second for working the auxiliary motors at full speed. The transformer connections are shown in Fig. 284.

FIG. 282.—Siemens-Schuckert Experimental 20,000-Volt Locomotive and Train.

Before dealing with the electrical equipment in detail, however, a word or two may be said with regard to the duty of the locomotive and its mechanical design. The locomotive weighs 36 tons, and is specially constructed for hauling goods trains at a speed of 45 km. (twenty-eight miles) per hour on the level, or 24 km. (fifteen miles) per hour on gradients of 1 per cent. Provision has been made for increasing the speed to 65 km. (just over forty miles) per hour by changing the gear. Behind the driver's cab is a large compartment which contains the transformer, switch gear and safety appliances, also two auxiliary motors for the pneumatic brakes and a cooling motor. The main motors are situated under this compartment, and, as will be gathered from the diagram of connections, Fig. 284, there are three motors.

Over the centre of the compartment containing the transformer, etc., there is a small superstructure, through which the high-tension leads pass. This serves to

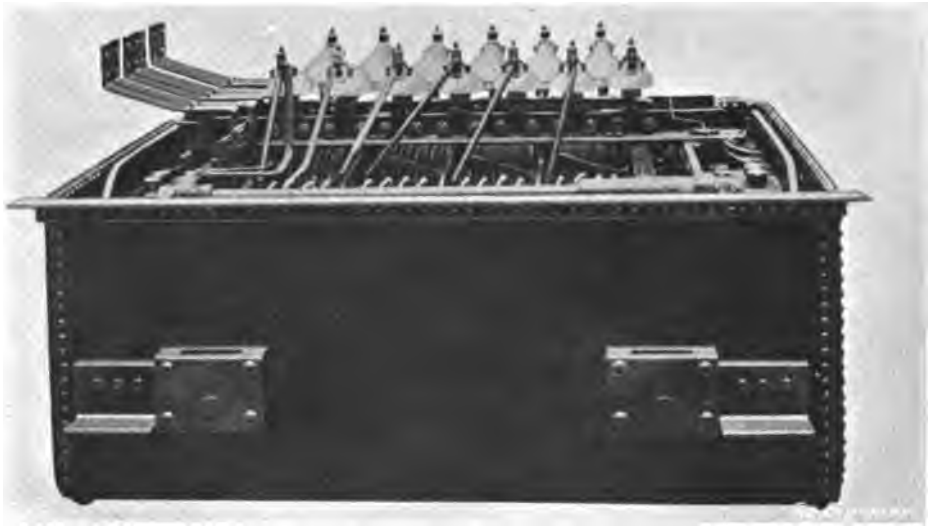

FIG. 283.—Transformer for 20,000-Volt Locomotive.

support the current collector, and is built so as to provide an inlet for the cooling air. The locomotive is equipped with automatic vacuum brakes which act on twelve brake blocks, giving a total braking pressure equivalent to 80 per cent. of the weight of the locomotive. Hand brakes operated by means of a wheel in the driver's cab are also fitted. Sanding gear is provided for the two front wheels. Each of the three axles is driven by compensated series motors fitted with commutating poles for preventing sparking.

As explained above, this locomotive was constructed for experimental purposes, and in order that it might be operated with the voltages mentioned, arrangements were made at the power house for supplying the various pressures for which the main transformer is wound. The primary winding of the transformer (shown in Fig. 283) is divided into eight 2,500-volt sections, so that when all these are connected in series the locomotive can be worked at $2{,}500 \times 8 = 20{,}000$ volts. It is, of course, understood that in the experiments referred to the primary transformer connections were arranged for the different experimental voltages at the commencement of each trial, and that no alteration of the primary connections was necessary whilst the locomotive was at work. It is quite unnecessary to enter into all the details shown in

the diagram of connections, since the general scheme of the wiring can easily be followed. It may be pointed out, however, that the controller consists of a main

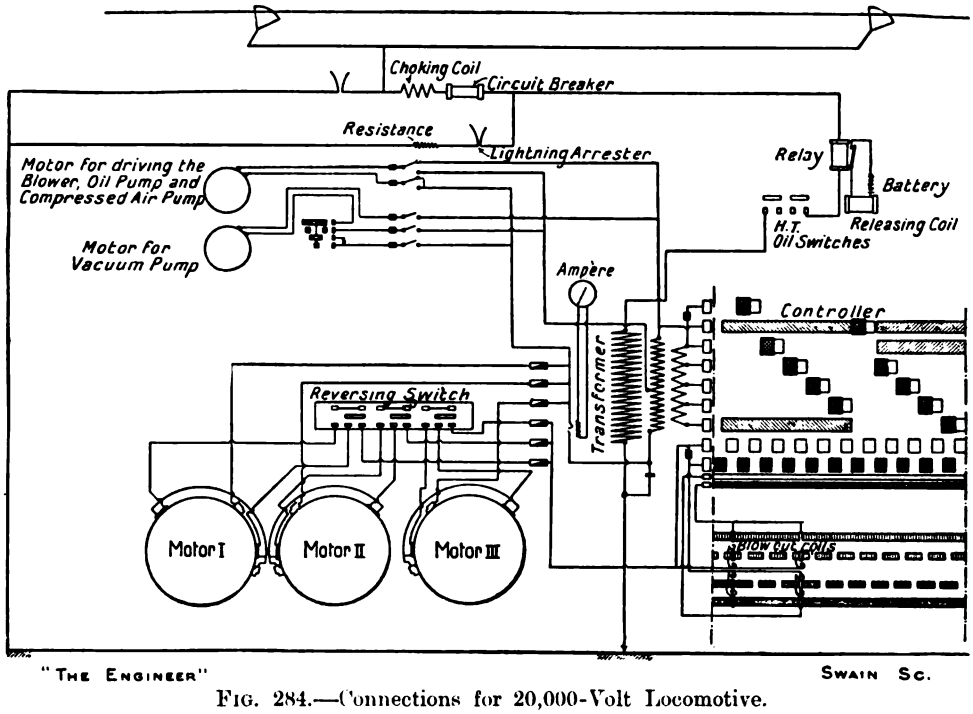

Fig. 284.—Connections for 20,000-Volt Locomotive.

barrel carrying contacts for altering the connections to the motors, and an additional small barrel on which the arcs are broken.

The controller, reversing switch and main air pump switch are all operated by hand without the intervention of compressed air gear or other similar arrangements. The handles for the three above-mentioned switches are interlocked, so that the reversing switch can only be moved when the current is cut off from the motors, and the main high-tension switch can only be closed when the main controller barrel is in the off position. Current is collected from the overhead wire by two automatic reversing aluminium bows mounted on frames, the spindles of which are coupled in such a way that the bows move vertically up and down. The frames are raised by springs and the bows held upright on the frames by separate springs. The pressure between the bow and trolley wire is the same at all heights, and the bow can be lowered by means of a cord leading to the driver's cab. From the bows the current is conducted to the transformer by means of bare rods mounted on insulators, and these rods pass through the superstructure to be seen at the top of the locomotive.

Fig. 285.—Motor.

A horn lightning arrester is fitted to the locomotive, one pole of which is connected

to the high-tension circuit and the other through a high resistance to earth. Each motor is rated at 110 h.p. at 320 volts and 25 periods. The gear is constructed so that the ratio can be changed from 1 : 5 to 1 : 3. An illustration of one of the motors as used on this experimental locomotive is given in Fig. 285. It will be gathered that forced ventilation has been adopted. The rotary blower, which is indicated on the diagram of connections, supplies air under pressure to each of the three motors. It runs at 1,725 revolutions per minute and delivers 40 cub. m. of air per minute at a pressure corresponding to 75 mm. water column. The power required for operating the blower is 1·8 h.p. Air is sucked in at the sides of the upper part of the locomotive, and in order to eliminate the presence of dust in the working parts it is drawn through a filter consisting of a series of small mesh sieves. It will be gathered from the illustration, Fig. 285, that the air enters the casings of the motors through pipes and leaves by way of slots, to be seen on the outside of the motor casing. The transformer is oil-cooled, and in order that the temperature may not become excessive the oil is circulated by a small pump. The pump draws the oil through cooling pipes round the outside of the locomotive. The motor which drives the blower and air compressor also serves for operating the oil pump. The small air compressor supplies compressed air to the whistle pipes.

Since this is an experimental locomotive it follows that the general construction differs somewhat from other locomotives which have been constructed for a specific purpose. The experiments carried out with this locomotive, however, went to show that the use of 20,000 volts on the trolley wire is quite practicable.

Various Railways.—The Board of the Swedish State Railways has just laid before the Government a plan for the electrification of certain sections of the State lines. The first of these to be electrified will be the eastern section of the Lapland railway from Kirunavaare to Gellivare, Lulea and Svartöw. Also it is proposed to extend the electric working of the Stockholm-Märsta section of the North Trunk line (proposed some time ago) to Upsala and Krylbo. Of railway lines south of Gothenburg it is proposed to electrify the Stockholm-Gothenburg line, the Katrineholm-Norrköping section, the Pärna-Nyköping-Malmö-Trelleborg sections, and the Gothenburg-Malmö line. For the provision and transmission of power for these lines two systems of transmission are to be employed, both starting from Trollhättan. The two systems of lines, which are to transmit energy at 80,000 to 100 000 volts, are to follow the railways as far as possible, and at about every 25 miles transformer stations are to be built to transform down to 15,000 volts, which is to be the working pressure. Provision is also to be made at these stations to supply current for lighting or power purposes to outside consumers.

CHAPTER X

THE PARMA SINGLE-PHASE TRAMWAYS

ALTHOUGH it is frequently stated that the single-phase system can only show an advantage when it comes to electrifying long-distance main lines, it has been shown that single-phase alternating current has been employed with marked success on traction systems which are really little more than tramways and where the rolling stock is very light. Perhaps the most interesting example of this description is to be found in the province of Parma, where the tramways are worked in this manner. Fig. 286 gives a map of these lines. It appears that the question of whether single-phase or continuous current should be used was gone into very thoroughly, and after a great deal of discussion a commission was appointed to settle this point. The outcome of this was that the single-phase system was recommended. The pressure decided upon for the outlying or country lines was 4,000 volts and for the town lines 400 volts. Attention has already been directed to the fact that the alternating-current system is particularly suitable where it is desired to use two distinct pressures, and several railways worked in this way have been described. In car sheds, for example, it is generally desirable to use a lower pressure than that employed on the lines outside, and with the single-phase system this can be arranged for without complicating the electrical equipment. In the case under consideration, however, the lower pressure is used on the town sections of the lines in the interests of public safety. The periodicity is 25 cycles per second. It was thought that the alternating-current system might interfere with the working of the telephones, but up to the present no troubles of this kind have occurred. The lines were put into operation in May, 1910, and Siemens-Schuckert carried out the electrical work.

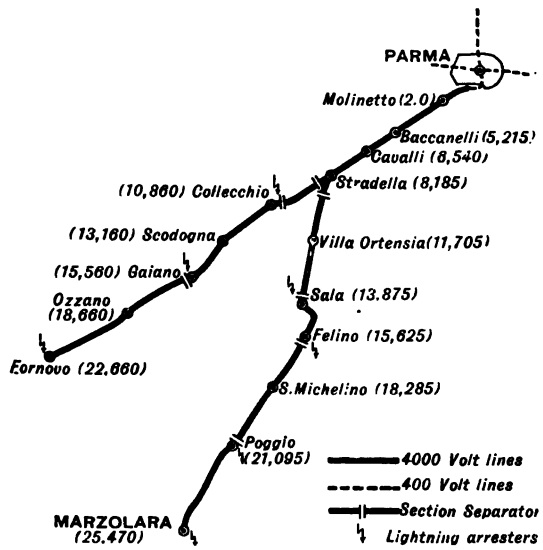

FIG. 286.—Plan of Lines.

Owing to the fact that a steam plant is used for supplying power to the system, it was necessary to erect the generating station in the vicinity of the town portion of the line, because this was the most favourable spot for obtaining circulating water for condensing purposes. The generating plant consists of two horizontal two-cylinder steam engines constructed by Franco Tosi, of Legnano, which run at a speed of 125 revolutions per minute. Each engine is coupled to a single-phase alternator having a normal capacity of 755 kilovolt-amperes at 4,000 volts, 25 cycles. The maximum load which can be put on the machines, however, is 1,000 kilovolt-amperes. There are also two vertical steam engines capable of developing about

55 h.p. Each of these engines is coupled to a continuous-current dynamo which works at a pressure of 110 volts. These sets are used for exciting the alternators and also for lighting the power station, car sheds, and workshops. The boiler-house contains four Cornish boilers, which work at a pressure of 180 lb. per square inch.

For the purpose of lowering the pressure to 400 volts for the lines in the vicinity of the town three oil-cooled transformers are used, each of which has a normal capacity of 45 kilovolt-amperes and a maximum output of 135 kilovolt-amperes. These have been erected in the power-house. Transformers of the same output are also provided at the four farthest points of the town network, and two or three of these can be connected in parallel as desired.

In the immediate vicinity of the power station there is a car depôt, as shown in Fig. 287, which has ten tracks 50 m. long. At this point there is also a goods station, workshops, and a large storage shed. The usual inspection pits are provided inside the car shed. The maximum height of the overhead wires above the rails is 6 m., but on the Milano-Bologna line the height is only 4·1 m. This portion of the

Fig. 287.—Car Depôt.

line is only subjected to pressure when a car is passing over it and at other times it is dead. In the car sheds the height of the wire is 5·5 m. There are also car sheds at the Marzolara Station, and here the height of the overhead wire is 5·1 m. The outlying lines have a total length of approximately 39 km. The smallest curve radius is 40 m., and the greatest speed is 40 km. per hour.

The high-tension overhead equipment was constructed by Siemens-Schuckert. On the straight portions of the line the points of suspension are 64 m. apart. An example of the overhead equipment on a straight portion of the track is given in Fig. 288. The suspension cable has a sag of 1·5 m. The auxiliary suspension wire is hung from points 16 m. apart on the suspension cable and the conductor at every 8 m. on the auxiliary wire. A copper wire having a section of 35 sq. mm. is used for the overhead conductor. This is stretched in accordance with the method adopted by Siemens-Schuckert. An example of the wire tightening gear is shown in Fig. 289. The counter-weights to be seen at the sides of the poles weigh 300 kilos. On the open track poles of chestnut wood are used, as shown in the illustration of the lines at Stradella, Fig. 290. At stations, however, iron lattice poles are employed, as shown in the illustration of the Fornovo Station, Fig. 291. The iron poles, brackets on the

wooden poles, and the supports on the houses, etc., are all connected to the rails by means of 8 mm. galvanised iron wire.

The rails are also well earthed at points 1,500 m. apart by connecting them to earth plates buried in moist soil. It will be gathered from the illustrations that double insulation is used throughout the high-tension overhead equipment. Section insulators are interposed in the overhead line at every intermediate station, which under normal conditions are bridged over in the usual manner. A section switch at Gajano is shown in Fig. 292. If necessary, any section behind a roadside station can be made dead. The horn switches are operated by means of poles. At the roadside stations lightning arresters are connected to the overhead lines. These are of the horn type, and in three places they are directly connected between the lines and earth. At eight other points resistances are used in conjunction with the horn lightning arresters, and in those cases there is a smaller distance between the horns. This system of protection is said to have proved very successful in practice. Roadside stations on the outlying lines are connected with Parma by telephones. There are also two other separate telephone lines, one between Parma and Marzolara and the other between Parma and Fornovo. The intermediate station, Stradella (see map, Fig. 286), is also connected by telephone to both branch lines. The telephone wires, which are of silico bronze, 1·5 mm. in diameter, are supported on the poles which carry the contact wire, as shown in Fig. 288. The two wires of each line are crossed at every second pole, representing a distance of 128 m. Small transformers, having a capacity of 1 kilovolt-ampere, are used at the stations for lighting purposes. Current for lighting is taken from the secondary windings at a pressure of 110 volts.

FIG. 288.—High-Tension Wires on Open Track.

The point at which the 4,000 and 400 overhead wires approach one another is in the immediate neighbourhood of the power station. At this point a change is also made in the form of the overhead construction, the latter being of the ordinary tramway type on the town lines. The transition point, as it is termed, is shown in Fig. 293. There is a dead section of line between the high and low tension wires, which is about 16 m. long. The town lines extend for a distance of about 12·5 km., the length of track, including the car yards, being about 14·5 km. They consist chiefly of main lines crossing at the Piazza and Garibaldi, in the centre of the town. One of these lines connects the Barriera Nino Bixio—the end of the outlying lines—with the State railway station, whilst the other passes through the town and runs to the great "Via Emilia," the principal street between the small towns of Reggio, Parma and Piacenza. Outside the town boundaries the lines are extended as far

as the neighbouring places of St. Lazzaro-Parmense, St. Leonardo and Crocetta. In addition, there is a circular line which connects the Barriera Garibaldi with

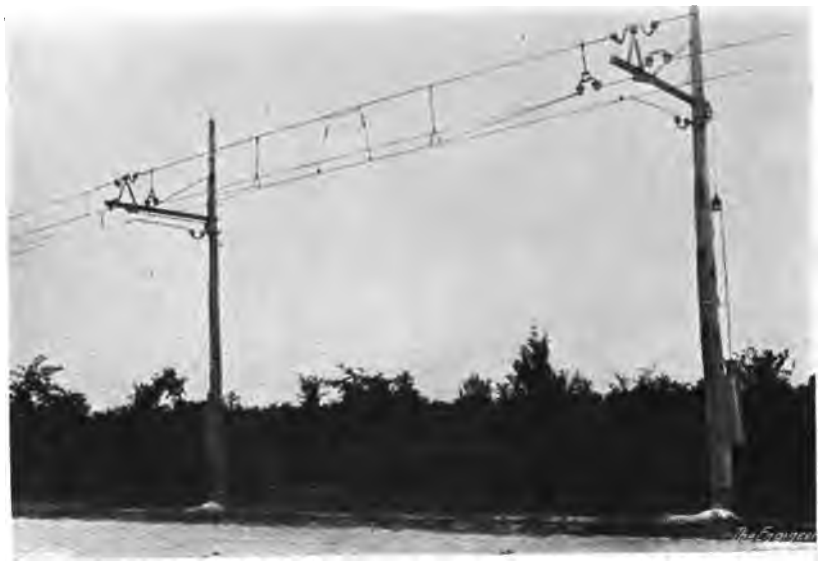

FIG. 289.—Wire Tightening Gear.

Barriera Vittorio Emanuele, as well as a connection from the Barriera Nino Bixio to the Friedhof.

On the town sections the overhead lines are constructed in accordance with the

FIG. 290.—Overhead Lines at Stradella.

usual practice adopted on tramways, and the bows on the cars are used for collecting the current, as on the outlying lines. In some cases the overhead wires are suspended

FIG. 291.—Fornovo Station.

FIG. 292.—Section Switch Post at Gajano.

from fittings attached to the houses, whilst in other instances poles with brackets are used. A view showing the overhead construction on one part of the town lines is given in Fig. 294. The section of the low-tension wires is 55 sq. mm. The 4,000-volt lines are fed at the beginning of the track near the Barriera Nino Bixio by means of an overhead line from the power-house. This line, which consists of a copper wire having a cross section of 95 sq. mm., is carried on insulators mounted on the lattice poles of the tramway system. Guard nets and short-circuiting hoops are provided for ensuring safety in the event of a wire breaking. The transformers in the town, on the other hand, are fed by means of a high-pressure cable having a total length of 6,300 m., which is laid underground. The primary return circuit is also through the cable, and is therefore independent of the rails. The secondaries of the transformers are connected to the low-tension overhead wires by means of a

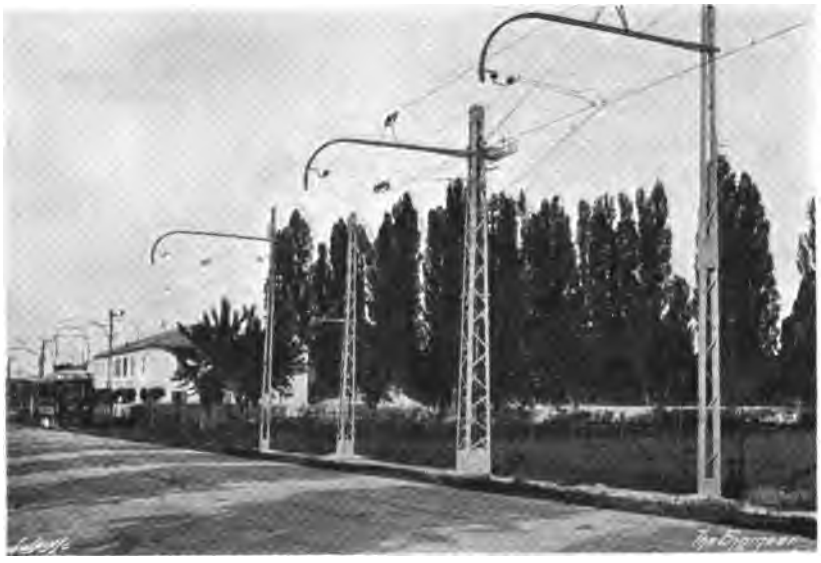

FIG. 293.—Meeting Point of High and Low Tension Wires.

rubber insulated cable, whilst the rails are connected to the secondary windings by means of tinned copper cable, which is laid in the ground.

For the outlying lines there are ten motor cars capable of seating seven first-class and twenty-one second-class passengers. There are also luggage compartments capable of carrying luggage up to a weight of one ton. A good deal of standing room is available in these cars. In addition, there are eleven passenger carriages, consisting of one saloon carriage with twenty-four seats, six second-class carriages with about thirty-six seats, and four second-class carriages with about twenty-eight seats. There are also goods trailer cars capable of carrying a load of about eight tons. A train as made up for heavy passenger traffic is shown in Fig. 295. It consists of one motor car and three trailers. A motor car with the high-tension chamber opened is also shown in Fig. 296, and a drawing of one of these cars is given in Fig. 297. The diameter of the driving wheels is 900 mm. Each bogie is equipped with a four-shoe brake. The wheel base measures 1·4 m., and the distance between the two driving axles is 5·5 m. The body of the carriage is 10·6 m. long, and the greatest length over the ends of the car 11·42 m. The total breadth is 2·31 m. The first-class compartment has transverse seats, and the second-class partly transverse

and partly longitudinal. Between the first and second class compartments there is the luggage space, which also serves for the mail bags.

Current is collected from the overhead wires by means of spring bows. They are raised and lowered by compressed air, and are controlled by means of a three-way cock in the driver's compartment. In order that the driver shall be able to operate the bows in the event of the air compressor equipment breaking down, a

FIG. 294.—Low-Tension Wires in Town.

hand-operated air pump is provided. The cars are also equipped with hand and air pressure brakes, the latter being of the Siemens-Schuckert type. Each motor car has two brake cylinders, both of which operate on the eight brake shoes of the car. By reason of the large quantity of air which the brakes of a motor car and three trailer cars require, each motor car is fitted with two main air reservoirs, each having a capacity of 100 litres. These two reservoirs are connected in series, this arrangement presenting the advantage that two places are provided for the oil, which leaves the compressor to deposit. There is thus less chance of its finding its way into the air brake conduits.

The electrical equipment of the cars consists of two Siemens-Schuckert series

motors, each having a capacity of 70 h.p. on the one hour rating. The remainder of the electrical equipment comprises the transformer for reducing the contact line

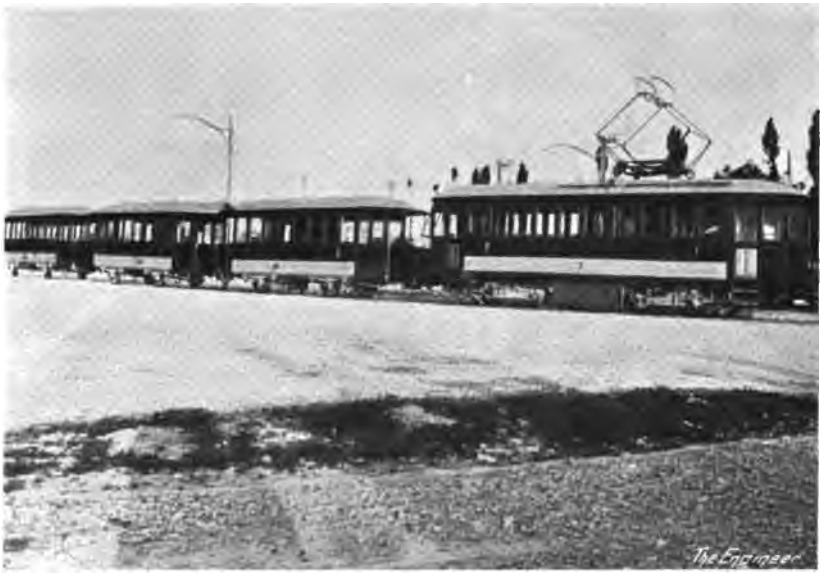

FIG. 295.—Motor Car and Three Trailers.

pressure, the controllers, which are similar to the ordinary tramway type, the motor compressor for the air brakes, the reversing switches, cut-outs, and lighting and

FIG. 296.—Motor Car.

heating apparatus. The high-pressure apparatus comprising the oil switch circuit breakers, etc., are placed in a high-tension chamber under the car. This chamber can

only be opened after the current collector has been lowered and after the high-pressure circuit has been earthed.

A diagram of electrical connections for a motor car is given in Fig. 298. Here A is the current collector, C the choking coil, D the automatic oil switch, E earth, F the switch for changing the connections for high and low pressure working, G the main transformer, G1 auxiliary turns on the main transformer connected with the motor windings, HH the main controllers, H1 the blow-out magnet, H2 the reversing drums, J a choking coil, K the low-tension current switch, M1, M2 the 70 h.p. series motors, N the air pressure cylinder for actuating the bow, O the switch for the air

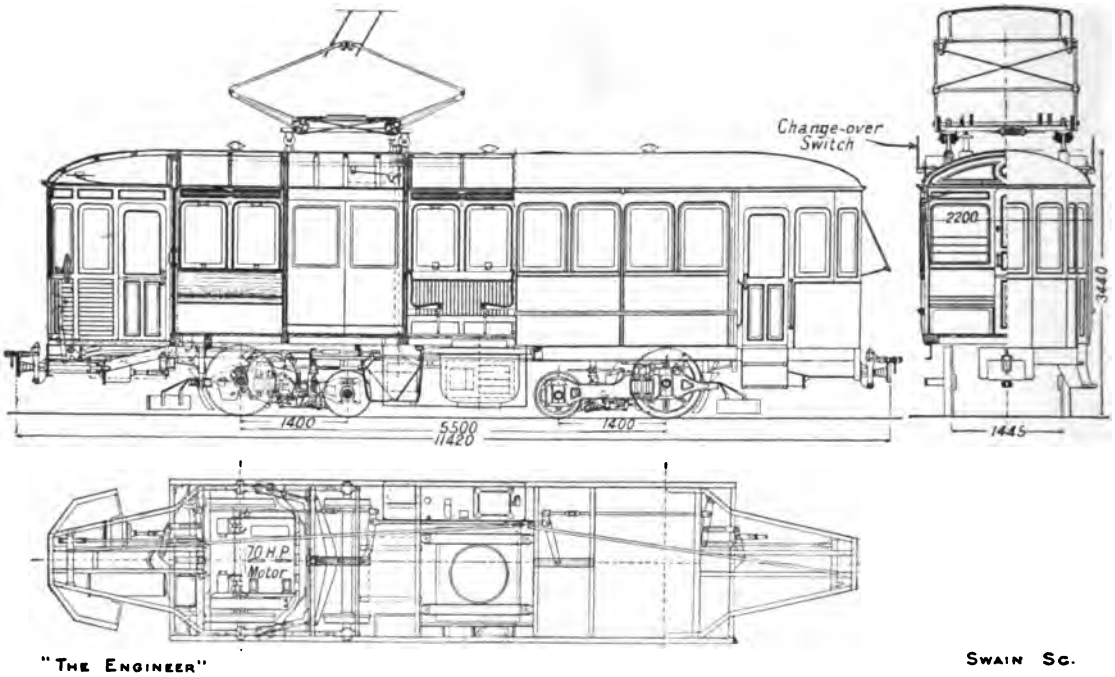

FIG. 297.—Motor Car.

pump motor, P automatic air pump switch, R1, R2 the brake cylinders, S cut-outs, T lamps, U heaters, and V a hand-operated switch for air pumps.

The main oil switch is provided with an electrically operated release gear, the relay of which is connected in series with the main circuit, so that in the event of the motors being overloaded the main circuit is opened. This action is independent of whether the car is working on the 4,000 or 400-volt circuit. The trip gear can also be made to actuate the switch by pressing a button in the driver's compartment. Moreover, the high-tension switch can also be opened or closed without the relay being brought into use, but this is not possible when the controller handle is in any of the running positions.

From the main oil switch the current is conducted to the change-over switch F which is used at the point of the line shown in Fig. 293, where the change in the working pressure is made. It will be gathered from the diagram of connections that when the cars work on the low-tension system the current from the overhead wire passes into the thick winding of the transformer, when the latter acts as an auto-transformer. When working on the 4,000 lines, on the other hand, the high-tension current is sent into the thin wire winding, when the low-tension current is

taken from the secondary of the transformer in the usual manner. When the cars pass from the low to high pressure sections of the line the change-over switch on the motor cars is actuated automatically, a lever on the cars striking a fixed point on the poles, shown in Fig. 293. The lever which actuates the change-over switch is to be seen on the top of the drawing, Fig. 297. When this lever comes into contact with the projection on the poles the change-over switch is thrown over by means of a counter-weight and spring, so that the switch blade fits into the high-pressure contacts. The

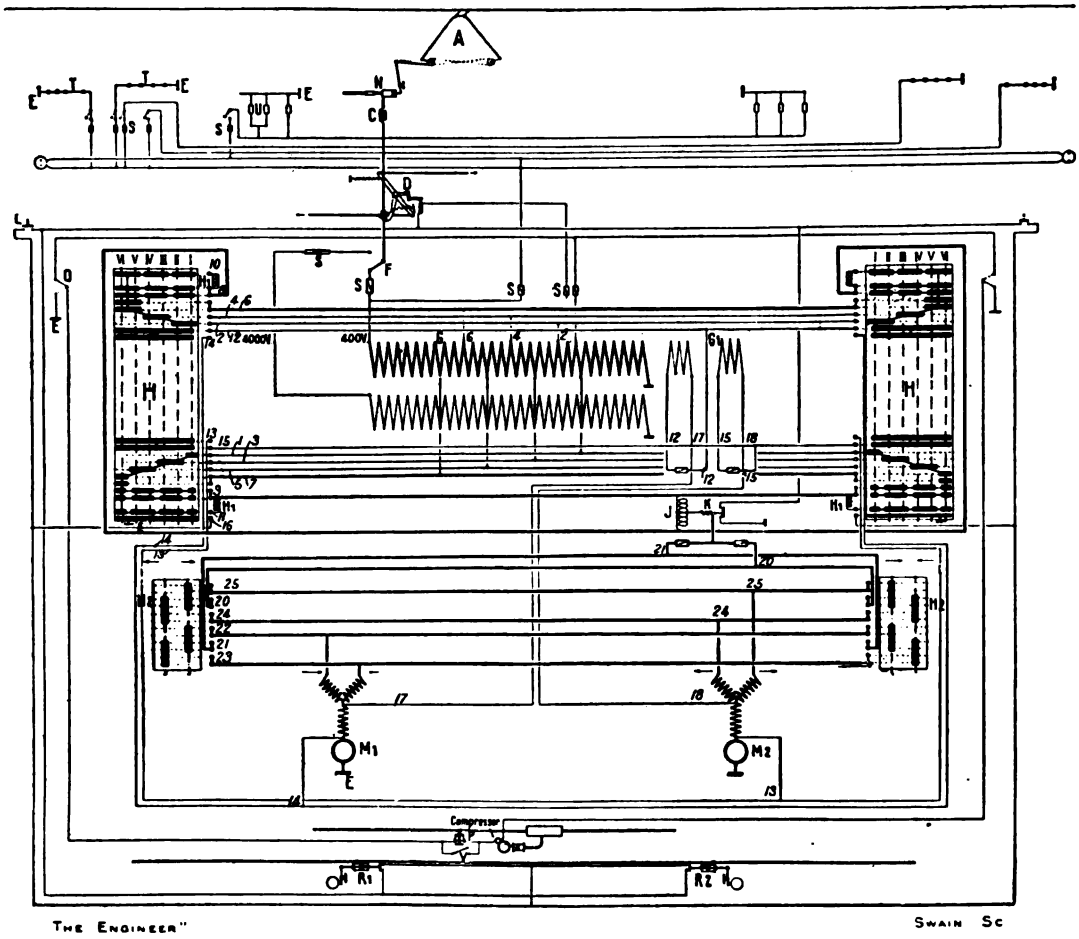

Fig. 298.—Connections for Motor Car.

change from high pressure to low, on the other hand, is effected by hand. This can only be done when the controller handle is in the "off" position.

The low-tension side of the transformer has six tappings giving pressures of 183, 217, 250, 284, 317 and 350 volts. The controllers differ from the ordinary tramway type in that there are two separate groups of contacts. The motors are six-pole series machines with auxiliary excitation for compensating armature reaction. The auxiliary winding is fed from additional turns wound on the core of the transformer. The lighting and heating circuits are worked at a pressure of 400 volts, four lamps being connected in series. The electric heaters are placed under the seats and the metallic cases are earthed.

CHAPTER XI

THE NEW YORK, NEW HAVEN, AND HARTFORD RAILWAY

In a letter to *The Times*, June 26th, 1912, Mr. W. S. Murray, the chief electrical engineer of the New York, New Haven, and Hartford Railway, wrote as follows:—"Our power house contains plant having a capacity of 45,000 h.p. for the generation of single-phase current. Our track equipment for 1913 will be 552 miles. Our locomotive equipment, including multiple-unit motor cars, will be 151 units, and our engine and motor car capacity for developing power will aggregate 128,800 h.p. The investment cost of the system will be between 75 and 80 per cent. of that required for an equal direct-current electrification. Our all-day efficiency is 15 per cent. higher than the direct-current third-rail system. These are some of the facts that indicate the faith the board of directors of the New York, New Haven, and Hartford Railway have shown in spending upwards of £3,000,000 on the single-phase system."

Practically all the railway service between New York and Boston, as well as the New England States, is over four lines of this railway. The trains pass into the Grand Central Station in New York City over the lines of the New York Central and Hudson River Railway, which is electrified on the continuous current system, and works at a pressure of 650 volts.

On leaving the Grand Central Station, the trains of the New Haven system pass over twelve miles of rails of the New York Central system, and are supplied with continuous current from a third rail. They then pass on to the New Haven rails at full speed, and receive alternating current at 11,000 volts from the overhead trolley wires, which extend for a distance of twenty-one miles to Stamford, a total distance of thirty-three miles from New York, this being the end of the initial installation of the single-phase system. At the time of writing the system is being extended from Stamford to New Haven.

Thus when this is completed the electrified zone will extend from New York to New Haven, and will include the Harlem branch, with its extensive goods yards already electrified. This latter branch, which is connected with the electrified main line at New Rochelle Junction, enables all shunting operations on the New Haven system to the west of Stamford to be carried out electrically. The directors of the New York, New Haven, and Hartford Railway have decided to electrify the main line between Boston and Providence, employing the single-phase overhead system, as now in use and under construction between Woodlawn and New Haven. The line will consist of four tracks. A large power plant is to be built at Readville, Mass., for the operation of the system. With the completion of the Boston-Providence section and the extension from Stamford East to New Haven, nearly half the distance from New York to Boston will be covered by electric trains. Pending the construction of a tunnel under Boston connecting the New Haven and Boston and Maine system, several lines at the South Station in Boston will be equipped for electrical working. The estimated cost is about £1,400,000.

The complete system fed from the common power house at Cos Cob comprises the main line of the New York, New Haven, and Hartford Railway between Stamford and Woodlawn, the six-line Harlem river, goods, and passenger connection from New Rochelle to the Harlem River Station, and the New York City and New York, Westchester, and Boston line running from the West Farms connection to the Harlem River branch up to White Plains, New York. Throughout this extensive area there is not a single sub-station. The pressure on the overhead wire is 11,000 volts and the periodicity 25 cycles per second.

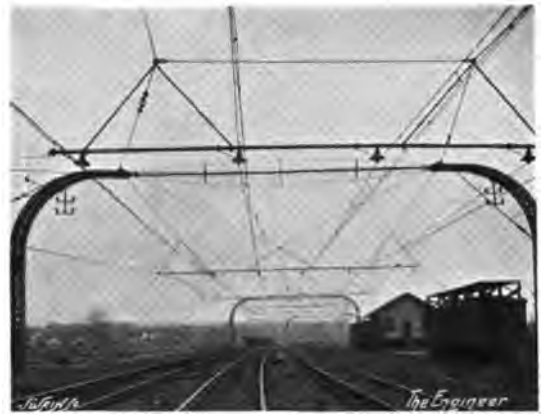

FIG. 299.—Overhead Construction.

The New Haven overhead construction as illustrated in Fig. 300 consists of a steel contact wire suspended every 10 ft. from a copper wire, which is in turn suspended at intermediate points from two steel catenary cables by triangular-shaped hangers. These cables are supported upon insulators resting upon steel bridges spaced at a distance of 300 ft. apart. A later type of overhead construction used on the Harlem branch is shown in Fig. 299. As there are generally four sets of rails, and sometimes more, the light steel bridges are made to span all the lines and to carry as many sets

FIG. 300.—Train on New York, New Haven, and Hartford Railway.

of conductors as there are tracks. Stronger bridges, to which the catenary cables are anchored, are erected about every two miles. At certain points these anchor bridges are utilised to support block signals and to carry

oil circuit breakers, which enable sections of the overhead wires to be disconnected. Under normal conditions all the overhead conductors and the supporting cables are connected together electrically and fed from the power house at Cos Cob.

In a paper read some little time ago before the American Institute of Electrical Engineers, Mr. W. S. Murray drew attention to the beneficial results which have been obtained from the use of the steel contact wire, and it was shown that the wear on the wire after it had been in use for a period of thirty months was only ·028 in., which is practically 4·5 per cent. per year of half the diameter of the wire. This would appear to indicate that the life of the wire is over twenty years. But Mr. Murray considers that it will last considerably longer than this, because as the vertical diameter is decreased the breadth of contact increases, thus diminishing the rate of the wear in a vertical direction.

Mr. Murray also draws attention to the fact that the wire is practically free from corrosion, as it is constantly covered with a film of grease, a generous amount of this material being placed on the bows of the locomotives and motor coaches. The steel wire acts as a longitudinal spring of constant length, and the tension only varies with the temperature. Since the coefficient of expansion of the contact wire and supporting catenary cable are the same, the difficult adjustments which are often met with when a combination of copper and steel is used are avoided. It was anticipated that owing to the smaller coefficient of expansion of steel as compared with copper, extreme variations in temperature might cause the contact wire to break, but, happily, this trouble has not manifested itself. Experience with this steel contact wire justifies its presence, and it is also used on the New York, New Haven, and Hartford branch and the New York, Westchester, and Boston section, thus serving for some hundreds of miles of single track.

When the problem of electrifying these lines first presented itself, Mr. Murray considered several distribution systems. Four of the systems which were gone into were as follows :—(A) The generation of three-phase current transmitted along the line at 11,000 volts and the pressure transformed down to 3,300 volts for use on the contact wires, the overhead lines being divided into three equal parts and each part supplied with current from the individual legs of the three phases. (B) The same arrangement as described above, with the exception that the step-down transformers supply current at a pressure of 6,600 volts. (C) Three-phase generation at 11,000 volts with 11,000-volt transmission along the track, the overhead conductors of the latter being divided into two equal parts, each part having its contact wires connected through the transmission lines to one of the three bus-bars at the power house, the remaining bus-bars being connected to the rails. These three schemes are shown in the diagrams 1, 2, and 3, Fig. 301. It is obvious that any division supplied with current from a given phase of the generators might be sub-divided into as many sections as desired. In the case of the fourth system (D) the current is generated at 11,000 volts and transmitted along the track at this pressure, but only one phase of the three-phase generators supplies current to the sectionalised sections of the overhead equipment. The three-phase lines, however, are extended throughout the electrified zone, and serve for supplying current to the polyphase motors in the workshops and for the operation of motor generators, etc., in connection with local direct-current railway plants. The diagram, Fig. 302, shows this system, which was applied originally to the railway with which Mr. Murray is connected ; this diagram, however, does not represent the present system.

The systems (A), (B), and (C) would appear to offer better opportunities for

distributing the load in the windings of the generators, but this is open to question on account of the possibility of unequal distribution of the trains on the sections fed from the three different phases. A disadvantage of three-phase distribution is that it introduces complications in connection with the overhead wires. Mr. Murray considers that for an equal weight of copper in the overhead lines, single-phase distribution is more efficient than any three-phase scheme. He believes that it is generally agreed that the single-phase system of distribution is the best. Recently, however, the running rails of this line have been connected to the centre points of 22,000-volt transformers. The new scheme is described in *The Engineer* of April 24th and May 1st, 1914. Although the pressure between the overhead wires and earth is still

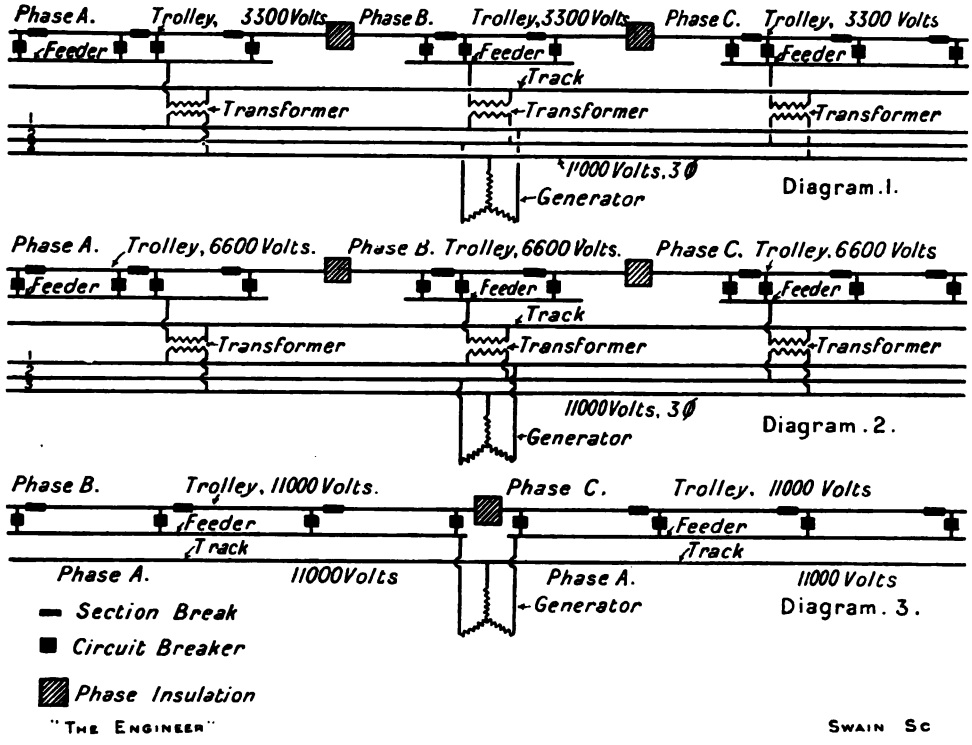

Fig. 301.—Distributing Systems Employing Three-Phase Generators.

11,000 volts, transmission of current between the generator and track is carried out at 22,000 volts.

A modification of the scheme (D) was at one time considered : it was proposed to generate three-phase current at 11,000 volts and to distribute single-phase current for traction purposes, the pressure being reduced along the line to 3,300 or 6,600 volts, and the current at this pressure supplied to the various sections of the overhead line. Apparently three-phase current would have been used for the shop motors, etc., as already described. It is obvious that three-phase current might be supplied to outside consumers. But owing to the fact that a shock from a 3,300 or a 6,600 volt line is almost sure to prove fatal, the use of 11,000 volts on the overhead lines did not appear to present any disadvantage from the point of view of safety. Moreover, the latter pressure obviates the necessity of erecting step-down transformers

along the line, lessens the current which has to be collected by the bows on the locomotives and motor coaches, and results in a greater overall efficiency.

Single-phase distribution facilitates sectionalising the line. As will be seen from the diagram, Fig. 302, the original system simply involved the use of two auxiliary wires AP immediately adjacent to the contact wires and the necessary switching apparatus. Although these auxiliary wires are called feeders, and whilst they obviously serve to increase the capacity of the overhead system, feeding is not their principal function, for the copper in the overhead contact lines is sufficient to prevent excessive loss. The auxiliary wires or distributors act as by-passes in the event of it being

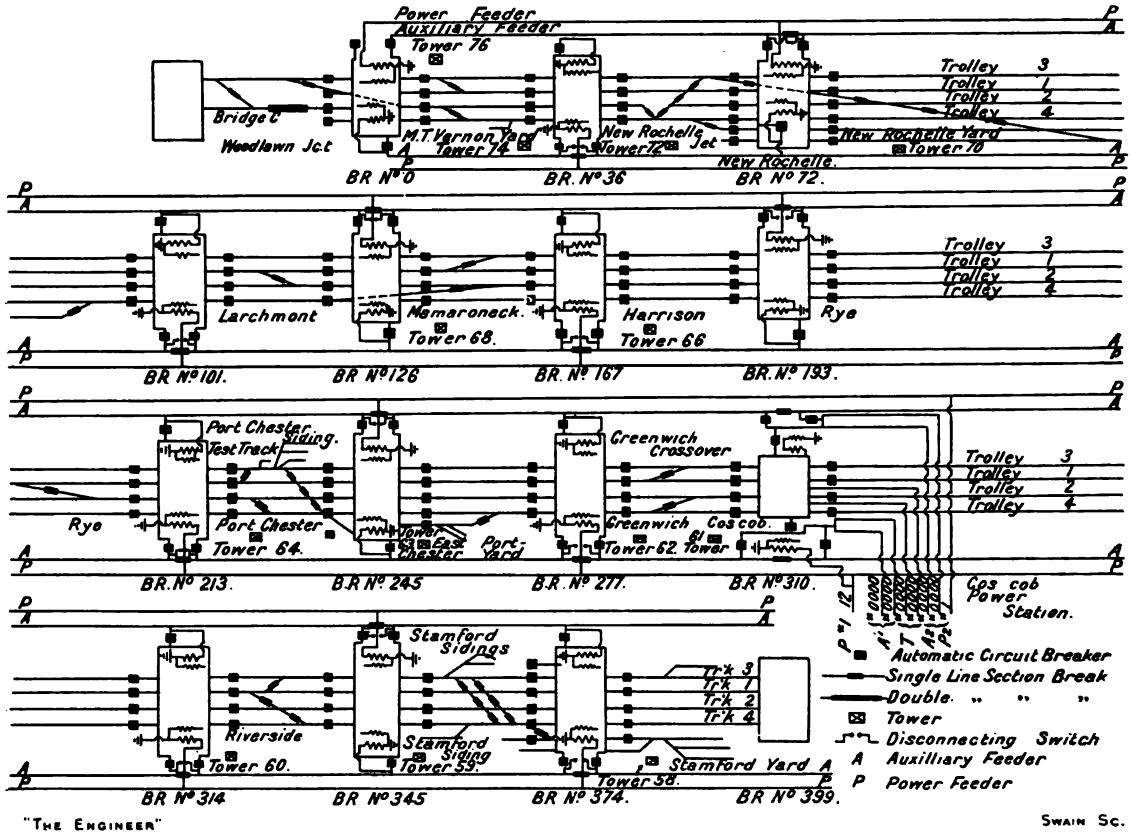

FIG. 302.—Original Distributing System on New York, New Haven, and Hartford Railway.

necessary to cut out any section of the contact wire. It is quite obvious that the provision of these additional wires enables the lines to be sectionalised to any desired extent, and that any section can be made dead without interfering with the working of the other sections.

Local conditions govern the lengths of the sections. In the case of the New York, New Haven, and Hartford Railway, no two of fourteen sections between Woodlawn and Stamford have the same length. The average length is 1·68 miles. No section is over 2·19 miles or less than 1·07 miles. It will be noted from Fig. 302 that of the fourteen sections between Woodlawn and Stamford, the ends of nine of them terminate at signal towers. In each of these towers or cabins there is a small switch panel, on which are mounted the pilot switches controlling the contact wire and by-pass circuit

breakers on the anchoring gantries. Apart from the economy of the system, this method of control enables the switching apparatus to be looked after by the signal operators, who, by reason of their experience with the operation of trains, have proved very suitable men to deal with the work.

Mr. Murray considers that it is preferable to specify the number of the sections to be used on a given line rather than the length of the sections. The length can be made to vary in accordance with the local conditions. When long sections are used, it is, of course, necessary to splice the catenary cables, as they could hardly be supplied in single reels in lengths of greater than two miles. But the splicing process does not present great difficulty, nor does it in any way interfere with the reliability of the overhead equipment. On the other hand, when short sections are adopted, a greater number of anchoring bridges are needed for the section switches. But these structures do not increase the difficulties of erection to any appreciable extent. Mr. Murray has come to the conclusion that the question of arranging the sections so that they terminate at the signal towers or cabins is by far the most important factor favouring the employment of a small number of sections.

By using a large number of sections, their ends might be at points between these signalling towers, necessitating some form of sub-station or building for the electrical operators. Moreover, by using long sections, the number of switches is reduced. Experience gained on the New York, New Haven, and Hartford Railway goes to show that the most satisfactory anchoring insulator from a mechanical standpoint is the corrugated cylindrical type. There is no doubt, however, that their insulating properties are less than those of the petticoat or mushroom pattern. Mr. Murray believes that by suspending some form of protective shield or petticoat from the anchor insulator much better insulation would be obtained. The blast from the steam locomotives has been found to give rise to a rough coating, which penetrates into the insulators and diminishes the insulating properties.

Long sections have the effect of reducing the cost of the switching equipment and of the bridges required for anchoring the lines. But a small number of sections increases the difficulty of locating earths, owing to the fact that there is a greater number of insulators between the circuit breakers. But on the New York, New Haven, and Hartford Railway this is not a serious matter, for it seems that a testing set has been devised which gives the position of a fault very accurately. Perhaps one of the greatest drawbacks attending the use of a small number of sections is that when a fault occurs a long portion of the line has to be made dead. The average distance between the cross-overs on the New Haven line is greater than the distance between the ends of the electrical sections, and consequently, in the event of a section being made dead, it is possible that a train might have to cross on to the other line at a distance from the fault greater than the length of the electrical section. Railway engineers, however, usually regard cross-overs as a necessary evil, and Mr. Murray does not consider that engineers would feel disposed to add cross-overs for the sake of reducing the length of the electrical sections. When the sections are long, the circuit breakers must have a larger current-carrying capacity than when short sections are used, but it is to be remembered that in any case the circuit breakers must be capable of dealing with the heavy currents which are set up by short circuits.

The American manufacturing companies have done a tremendous amount of work in developing single-phase locomotives and motor coaches. It has been found that a low centre of gravity is a decided disadvantage, and as a result many schemes have been tried for transmitting the power from the motors to the driving wheels.

The problem has been to find a satisfactory method of connecting the motors with the wheels so as to obtain a high speed without damaging the track. This has

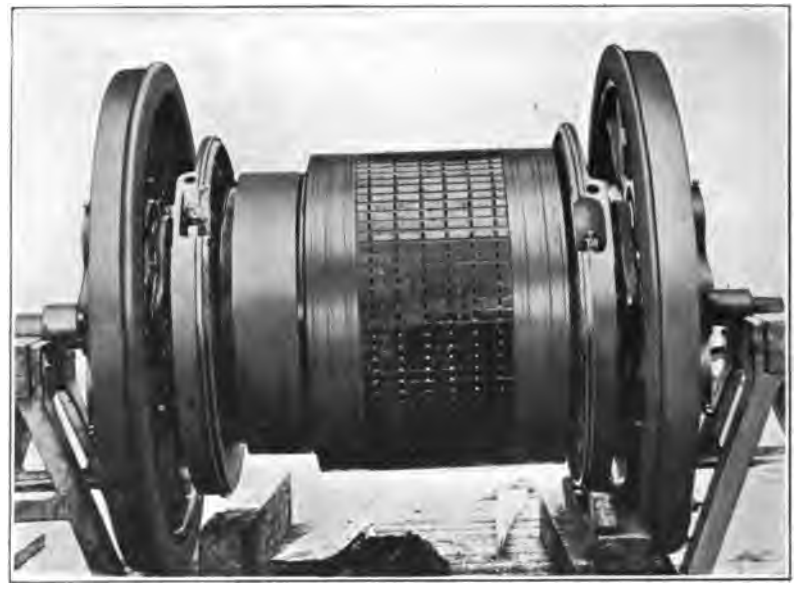

FIG. 303.—Armature and Driving Wheels.

resulted in the evolution of several distinct types of electric locomotives, including those with the motor armature mounted rigidly on the driving axle, and those with the armature mounted on a quill surrounding the axle (see Fig. 303). There are also locomotives with the motors geared to a quill surrounding the axles, this quill being connected to the wheels through long helical springs (see Figs. 304, 305). This design has been embodied in the latest type of engine put into service on the New York, New Haven, and Hartford Railway.

FIG. 304.—Westinghouse Spring Driving System.

It has been found that the practice of mounting the motor directly on a quill surrounding the axles and connecting the quill to the axles by springs is liable to some of the objections of the first-mentioned type. This system gives a low centre of gravity, but the weight is supported on springs, so that the rails do not receive the direct blow. The original New Haven locomotives nosed badly at high speeds, but by the addition of an idle axle at each end of the engine and a toothed cam centering device between the cab and the trucks this was entirely cured. The cam is

arranged so that when the truck moves sideways it must lift the cab, which tends to throw the truck in the central position. After this device had been applied a test speed of ninety miles per hour was obtained with practically no nosing. The

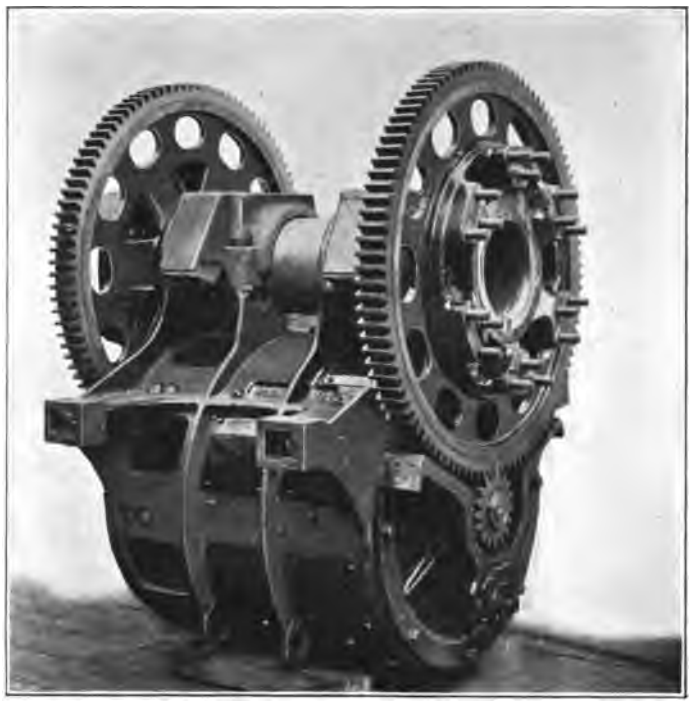

FIG. 305.—Gearing and Motor.

device is shown in Fig. 306. It will be seen that the cam is pivoted on the pony truck frames, and that by means of semi-circular teeth it meshes with a side-bearing rack on the main frames. The eccentricity of the cam prevents the pony wheels having radial movement, and the weight on the cam tends to restore the wheels to their normal position when on straight track. This is further illustrated in Fig. 307. Every locomotive now built for the New York, New Haven, and Hartford Railway has its motors mounted on a quill with springs. The motors are now placed above the axle, and drive gears mounted on the quill. This type of engine has a high centre of gravity, and the quills are so spaced that they have a total play of 3 in. about the axle (1½ in. above and below), which allows for irregularities in the rails. They are in service on the New Haven Railway and in the Hoosac tunnel on the Boston and Maine line. This type of locomotive has been built with a single motor per axle and with twin motors with the same total capacity per axle. After a number of locomotives had been constructed with very large motors, necessitating the use of double gears, it was found that the same output could be obtained with less weight and less cost by substituting two motors for the one of larger size. Various advantages have

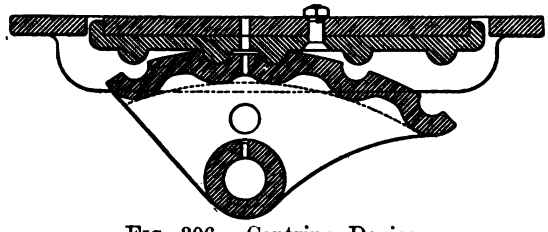

FIG. 306.—Centring Device.

been secured by adopting this arrangement. Firstly, only one gear is required, as both motors drive through the same spur wheels; secondly, the two motors are lighter, more easily handled, and cheaper to maintain; thirdly, the parts of the motors in this case are interchangeable with those of the motors which are used on the New Haven multiple-unit coaches; fourthly, since the two motors are permanently connected in series, the combination is equivalent to a single motor of twice the ordinary voltage, and consequently only half the amount of current has to be dealt with as compared with that taken by a single motor of the same output as the pair.

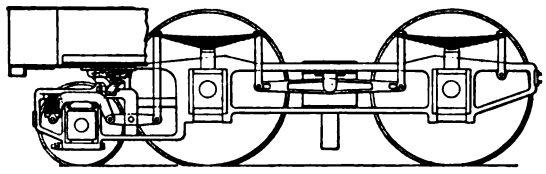

FIG. 307.—Truck.

Locomotives with the motors mounted high up in the cab and connected to the driving wheels through cranks, parallel rods, and a jack shaft, are used by the Pennsylvania Railway for the New York terminus. These engines have a very high centre of gravity, and, although the weight on the driving axle is about 56,000 lb., necessitating stiff springs, the locomotives have driving qualities corresponding to the

FIG. 308.—Shunting Locomotive.

best steam engines. They have no tendency to swing sideways, and, consequently, they do not damage the track. These are the most powerful D. C. electric locomotives that have been built.

Locomotives and motor coaches are used on the New York, New Haven, and Hartford Railway; the latter are employed in conjunction with trailer coaches on the suburban sections. The alternating current is collected from the overhead trolley wire by a pantograph collector. The continuous current, on the other hand, which is used in the New York Central zone, is derived from a third rail, and is collected by ordinary sliding contact shoes. Both collectors are brought into use by

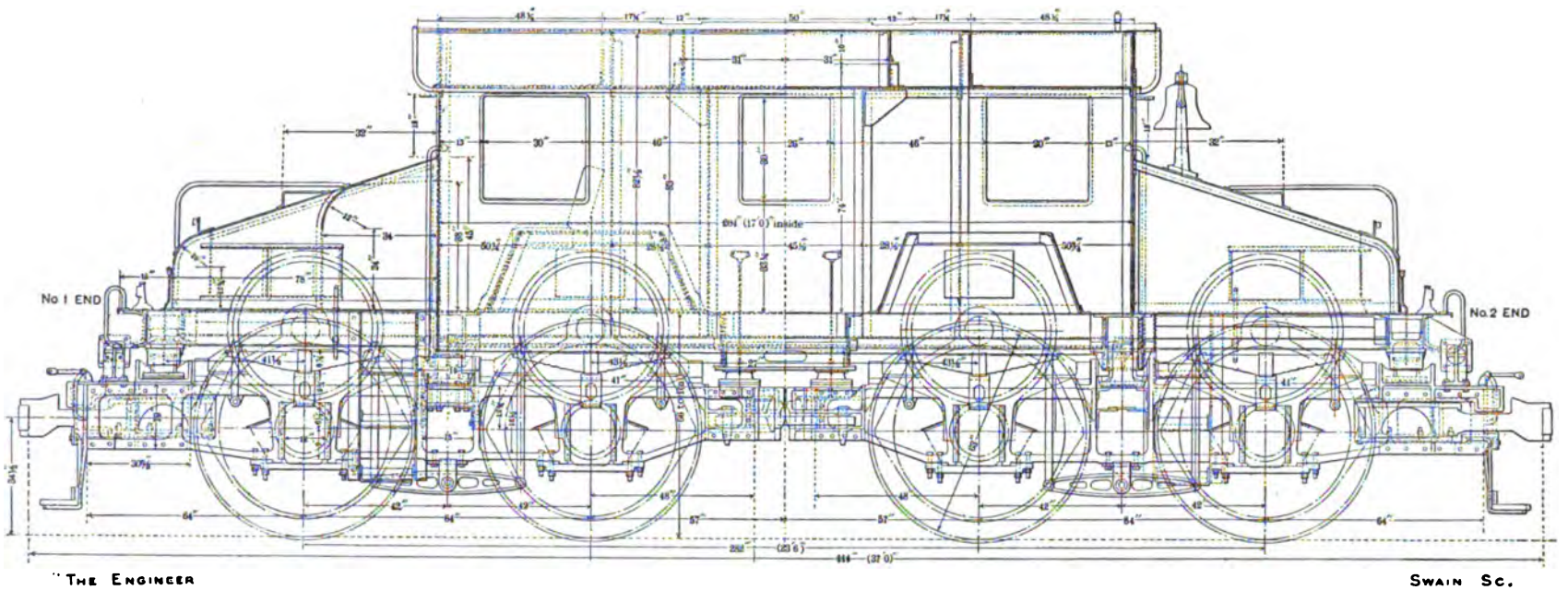

FIG. 309.—Shunting Locomotive, New York, New Haven, and Hartford Railway.

compressed air. Owing to the fact that the locomotives and motor coaches have to be operated with continuous and alternating current, a great deal of experimental work appears to have been necessary, and many changes in the mechanical and electrical equipment have been made. It seems, however, that the equipment has been very much simplified, and, notwithstanding the disadvantages attending a dual system, very good results are now secured.

At the time of writing no fewer than eighty-two electric locomotives have been purchased by the New York, New Haven, and Hartford Railway, all of which have been built jointly by the Baldwin Locomotive Works and the American Westinghouse Company. Fig. 308 shows one of the shunting locomotives, Fig. 309 a drawing of an engine of this description. It is of the quill spring-supported type, and the framework is of particularly substantial construction. There are sixteen of these locomotives, and

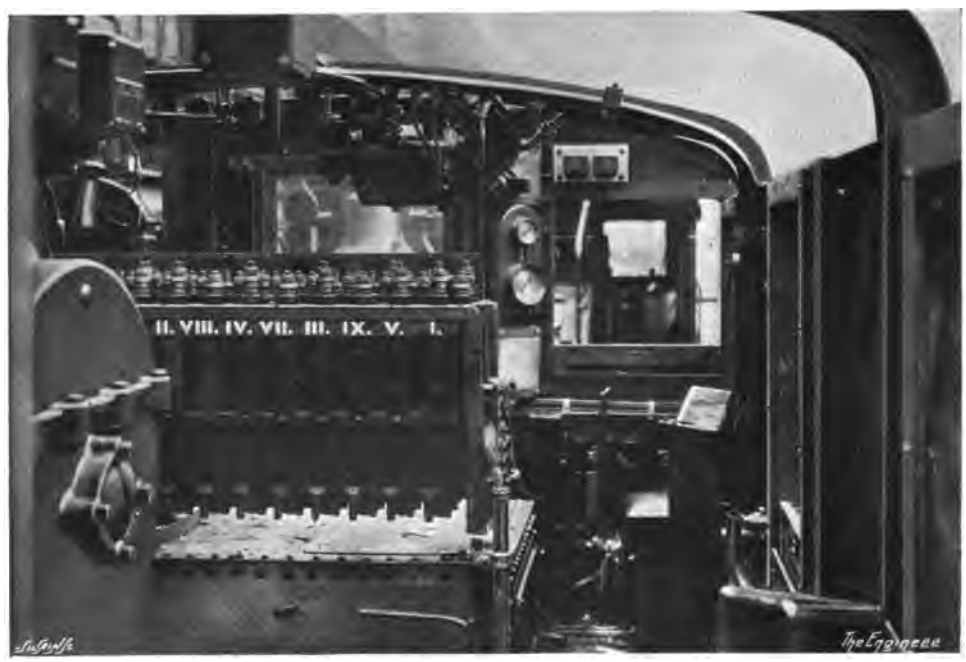

FIG. 310.—Interior of Shunting Locomotive.

they are of the eight-wheel articulated-truck type, with a central cab and sloping ends. The pulling and buffing stresses are taken by the truck frames, which are joined in the centre of the locomotive by a draw-bar. It will be noticed that the frames are outside the wheels, and the springs are placed directly over the journal boxes; the springs of the two trucks are connected together by equalising levers. A pinion is mounted on each end of the armature shaft, and each meshes with a steel gear rigidly mounted on a quill which surrounds the axle with a clearance sufficient to allow for vertical wheel play. The quill is carried in journals formed in the motor frame, and the power from the motors is transmitted from the gears to the wheels through helical springs rigidly attached at their ends to the wheel centre and gear centre respectively. Thus the motors are spring supported, and the centre of gravity of the engine is at a fair height above the rails.

To facilitate the removal of the electrical equipment, the roof of the locomotive

is designed so that it can be lifted, thus giving easy access to the transformer, compressor and other apparatus. In the case of the end motors, however, which, as can be seen from the drawing, Fig. 309, are under the sloping hoods, it is possible to handle these by a crane after the hoods have been removed. Owing to the fact that these shunting locomotives only operate on the New Haven system, the electrical equipment is very simple, since no provision had to be made for collecting the current from a third rail. Each locomotive weighs between 72 and 73 tons. The motors are arranged in pairs, and the connections are such that two of the motors are permanently connected in series and two in parallel.

Speed control is effected by means of tappings brought out from the secondary side of the transformer. Fig. 310 shows the interior of one of the shunting locomotives which is equipped with four 110 h.p. motors. There are twelve contactors and, as in all the Westinghouse locomotives, the contactor switches are operated by compressed air. A small 20-volt storage battery is used for actuating the electromagnetic valves. For charging the battery a small motor generator set is used. Under ordinary conditions this set provides all the power required for the control gear, the battery merely floating on the circuit ready for use in the case of accident to the motor generator set.

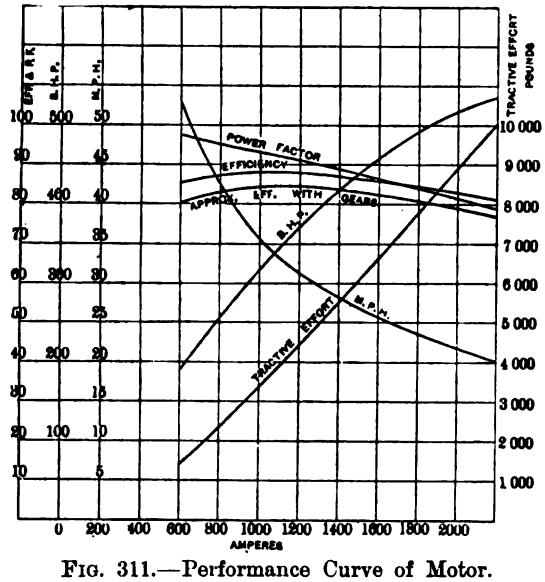

FIG. 311.—Performance Curve of Motor.

A particularly interesting feature is the provision of a temperature indicator which shows the temperatures of the motors. This enables the driver to ascertain when an engine is in a fit condition for hauling extra heavy loads. Most of these shunting locomotives are fitted with a master controller at each end of the cab, but a new type has recently been put into service. It has only one controller, which is placed in the centre of the cab, and serves for controlling the engine when travelling in both directions. All the shunting locomotives are guaranteed to exert a maximum tractive effort of 36,000 lb. for three minutes at a speed of six miles per hour, and a continuous tractive effort of 14,800 lb. at a speed of eleven and a half miles per hour. It has been found that an electric shunting locomotive can perform the work of two steam engines, because it can be worked day and night. The first shunting locomotive supplied has been in use twenty hours a day, and up to November 22nd, 1911, it had covered 13,000 miles. During this period it required no attention beyond the ordinary inspection. This engine is fitted with four 110 h.p. motors. When the full pressure of 240 volts is applied to the terminals of the motors, the current input is 900 amperes, corresponding to 192 h.p. per motor. Under ordinary shunting conditions, however, the maximum voltage is never reached, but it is only brought into use when the engines are hauling trains on gradients. The average pressure applied to the terminals of the motors is 190 volts, which corresponds to 123 h.p. per machine.

Turning now to other locomotives in use on the New York, New Haven and Hartford Railway, the curves given in Fig. 311 show the speed power characteristics

of a motor as used on the 071 type of goods locomotive, this curve having been reproduced from the paper by Mr. Murray already mentioned. This is a 25-cycle 300-volt machine, the maximum working current being 1,000 amperes. The continuous capacity is 300 volts, 930 amperes. The gear ratio is 34 : 79, and the diameter of the driving wheels 63 in. A record of a test on a locomotive of this type is given in the paper. The electric locomotive hauled a steam locomotive and thirty-seven coaches, the total weight of the train being 1,438 tons. The average speed over a distance of 1,675 miles was 36·5 miles per hour, the average kilowatt input being 1,487 kw. The average power at the rims of the driving wheels was 1,650 h.p., and notwithstanding that the electric locomotive was hauling an engine without steam it accomplished work with an average input of energy of 25·9 watt-hours per ton-mile.

Fig. 312 shows the 072 type of locomotive, and the drawing, Fig. 313,

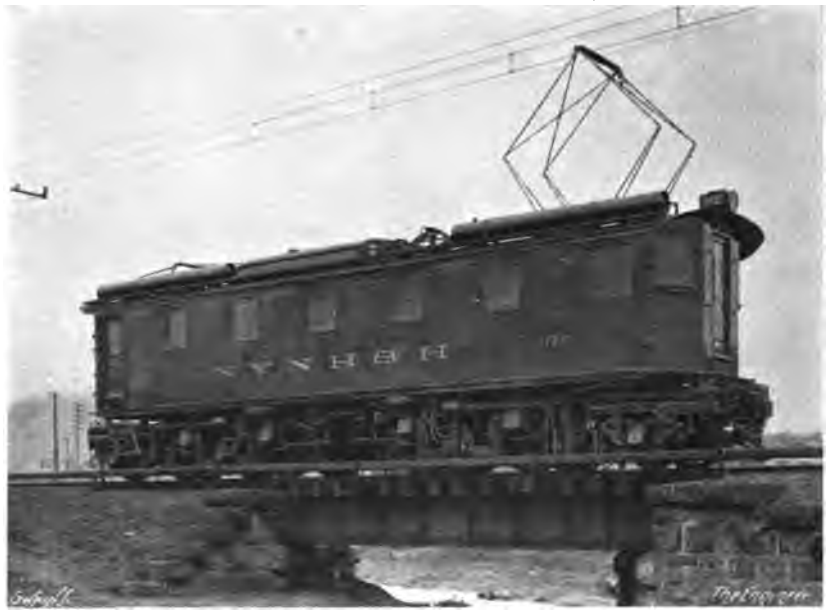

FIG. 312.—Locomotive, Type 072.

the 071 type, which was put into operation in the early part of 1910. The mechanical portion in each case was designed jointly by the Baldwin Locomotive Works and the New Haven Railway Company, and the electrical equipment was supplied by the American Westinghouse Company. From the illustration of the chassis of the 071 type (see Fig. 314) it will be seen that the engine is of the articulated truck type. The total length of the cab is 44 ft. Each truck is of the radial swing bolster type, and has two pairs of drivers. The trucks are coupled together and are equipped with Westinghouse friction draught gear attached to couplings at each end of the locomotive. The driving wheels are 63 in. in diameter, and the pony truck wheels 42 in. in diameter. The total weight of the locomotive is 150 tons. Instead of being carried on the centre truck pins the weight of the cab is supported on friction plates at the ends of the trucks, and the weight is applied to these through springs, which allow for variations in the track without materially changing the distribution of weight on the ends of the truck. But at

the same time the friction of these plates exercises a steadying effect on the locomotive and effectually prevents periodic vibration.

There are four motors, and each is rigidly mounted on the truck frame and directly above a quill surrounding the driving axle, to which it is geared. The quill drives the wheels through a system of helical springs. This arrangement allows a maximum movement of 1½ in. above or below the centre of the axle. Twin gears

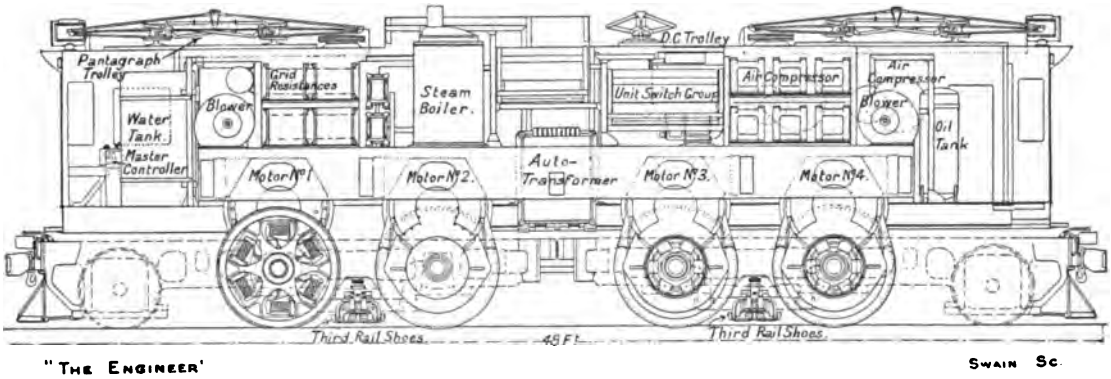

FIG. 313.—Details of Locomotive, Type 071.

are used on each motor. The rigid wheel base of the locomotive is 7 ft. for each truck. Thus the engine can negotiate curves quite easily. The drawing, Fig. 313, will assist readers to understand how the motors transmit their power to the driving wheels. As explained already, each motor is connected to its respective set of driving wheels through twin spur gears, a quill, and helical springs.

The latter are shown in connection with the motor marked No. 1. The master

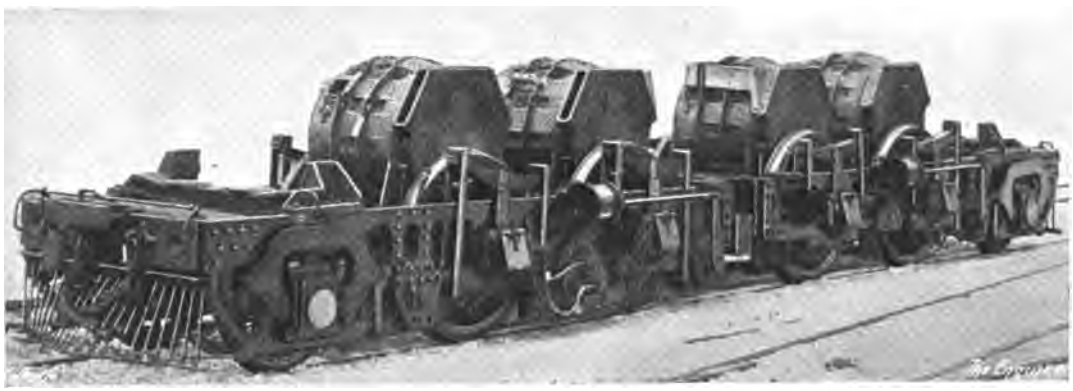

FIG. 314.—Chassis of Locomotive.

control apparatus, meters, air brake, valve, sanding foot lever, etc., are in duplicate at each end of the cab, and the contactor connections are arranged for multiple operation of the locomotive from a single master controller. To economise space the main air reservoirs are mounted on the roof of the cab at either side of the bow. This method of mounting the motors rigidly on the truck frames and above the axles gives a high centre of gravity.

The locomotive is fitted with two 11,000-volt pantograph current collectors,

and either of these can be raised or lowered as desired. As explained above, the locomotives have to work with alternating and continuous current, and to enable the engines to take up the latter current, four sets of sliding shoes are provided. When the engines are working with alternating current, the shoes are lifted, and are brought up close to the underframe of the engine. At crossings, etc., in the continuous current zone, an overhead conductor is used, so that the locomotives are also provided with a continuous-current collector as shown in the drawing. The control of the motors is accomplished by electro-pneumatically operated contactor switches, and the system enables two or more locomotives to be operated together from one master controller.

Besides the above-mentioned equipment the cab also contains a steam boiler and storage tanks for water for heating the passenger trains, but it is, of course, obvious that no heating arrangement is needed on the locomotives which are used for goods

FIG. 315.—Locomotive, Type 069.

trains only. When the locomotives are worked with continuous current the motors are connected in two pairs, and the two motors in each group are connected in series. The control is effected by the usual series parallel system. When the engines work with alternating current, on the other hand, all the motors are connected in parallel. In either case, a faulty motor can be cut out, whilst the other three remain in service. The change from alternating to direct current is accomplished by means of a set of double-throw switches, which are mounted on a board near the centre of the cab.

When the locomotives are using continuous current, the starting current is limited by resistances in the usual manner, and when using alternating current the pressure at the motor terminals is changed by bringing different tappings from the transformer into use. On turning the controller handle from the first to the full-on position thirteen different voltages are applied to the terminals of the motors, so that the speed of the latter increases smoothly and not in sudden jumps. The transformer is placed in the centre of the cab.

The specification for this type of locomotive stated that the engine should

be able to haul a 1,500-ton goods train at a speed of thirty-five miles per hour on the level, and where the train resistance does not exceed 6 lb. per ton. It was also specified that the engine should be capable of hauling the heaviest New Haven passenger train, weighing 800 tons, at a speed of forty-five miles per hour. In other words, this type of locomotive is capable of hauling an 800-ton passenger train between the Grand Central Station, New York, and New Haven, a distance of seventy-three miles, in one hour and fifty minutes, provided that no stops are made in the course of the journey. When stops are made at the five principal stations the time occupied in covering the seventy-three miles would be two hours twelve minutes. The specified time for 350-ton trains in local passenger service and stopping at all stations is two hours forty-five minutes, the time allowed for each stop being forty-five seconds. During a test, a locomotive of this type started and accelerated a 2,100-ton goods train both on the level and on a gradient of 3 per cent. on a 3 degrees curve. An 800-ton passenger train was accelerated at the rate of about ·4 miles per hour per second, thus quickly reaching the required speed. Each motor has a one-hour rating of about 375 h.p., and a continuous rating of approximately 310 h.p.

FIG. 316.—Twin Motors.

A later locomotive, designated type 069, is shown in Fig. 315, and a pair of motors as used for propelling it in Fig. 316. An end view of a locomotive of this type is shown in Fig. 317. The design of this engine, which is known as the Colonial type, differs considerably from that of the engine just described, and possesses a number of interesting features. The wheel base is really composed of three separate bases, namely, two four-wheel radial trucks and the remaining structure and its two pairs of rigid drivers associated with the locomotive's main framing and cab. The total wheel base measures 39 ft., and the length of the maximum rigid wheel base is 11 ft. It will be gathered that the cab and superstructure are built directly on the main frame and are integral with it. In the case of this type of engine the builders appear to have made a determined effort to reduce the weight. The frames are of steel plates, 34 ft. 4 in. long, $\frac{7}{8}$ in. thick, and 36 in. wide throughout the greater part of their length.

With the object of reducing the weight, the plates have been cut away wherever possible. This also gives accessibility to the journals and to the interior of the locomotive. The side frames are placed outside the wheels, axles, and axle-boxes, so that the locomotive can be jacked up and the wheels removed with ease. There are no pedestal caps in the main frames, and the light safety straps under the boxes can be removed without impairing the strength of the structure. The rigid drivers are guided in the frame by cast steel pedestals riveted and braced to the inside faces of the frame plates. Cross struts composed of steel plate secure the two frames together transversely, and also support the superstructure and motors. At each end the frames are tied by a cast steel bumper which serves four purposes. It ties the ends of the frame together, takes the draw bar pull, transmits the buffing strains to the main frames, and transmits part of the superstructure weight to the trucks.

The construction forms a boxlike structure, which provides a good foundation for the motors and other apparatus as well as a suitable frame.

The four-wheel radial trucks are secured to the main structure by two links situated ahead of the driving wheels. The radial links also act as draw-bars between the trucks and the main frame. They are slotted at one end so that they are relieved of the compression strains when the locomotive is subjected to buffing shocks or when it is pushing a train. At the back of each truck two steel lugs are secured to the channel iron, and these serve to keep the rear end of the truck in alignment with the main structure. These lugs, which are interposed between chafing plates, are carried on one end of the main frame cross ties, and they also serve as supports for the ends of the truck frames.

FIG. 317.—End View of Locomotive, Type 069.

To ensure alignment of the trucks and cab, cam rollers are fitted, and are so arranged that on straight track the entire wheel base of the locomotive is virtually rigid. A comparatively small force is sufficient to swing the trucks on cross-overs, etc. Locomotives of this type are said to run very steadily. The pony wheels and drivers in each truck are equalised together and also with the adjacent pair of drivers in the main frames. This is said to provide a symmetrical equalising system at each end of the locomotive. The length of the cab, which is built on supports directly secured to the main frames, is 40 ft., and there is a door at each end.

These locomotives are fitted with eight motors, and they are coupled in pairs, as shown in Fig. 316. Each pair of motors is permanently connected in series, and when working with continuous current the two motors of each unit are supplied with current at 600 volts. Therefore under these conditions there is a pressure of 300 volts across the terminals of each individual motor. It follows that when operating with continuous current the four pairs of motors can be controlled in the same way as the motors of a standard continuous-current locomotive, *i.e.*, the four pairs can first be connected in the series parallel fashion and then all in parallel.

Moreover, the system presents advantages when working with alternating current, since the voltage on the secondary side of the transformer is higher than would otherwise be practicable, with the result that the low-tension switches, etc., deal with a smaller current. When operating with alternating current the connections to the motors are precisely the same as those of the shunting locomotives, except that there are four pairs of motors instead of two. Contactor control is employed, and any pair of motors can be cut out of action in the event of failure.

Even when one pair of motors is put out of service, three-fourths of the hauling power can still be developed, whereas one-half of the equipment would be rendered idle in the usual two-motor or four-motor locomotive. The power for operating the various electro-magnetic valves, etc., in connection with the contactors is derived from a small 20-volt accumulator, which is charged by a motor generator, as described in connection with the shunting locomotives. Locomotives of the type now under consideration are designed to exert a continuous tractive effort of 12,000 lb. at a speed of thirty-five miles per hour, and a maximum tractive effort of 40,000 lb. The total weight of these engines is 116 tons. Each pair of motors, as shown in Fig. 316, is mounted above the axles, and, as already stated, there are eight motors in all.

Each motor shaft is provided with a pinion, and, as shown, the two pinions of each pair of motors mesh with a single spur wheel which is mounted on a quill surrounding the axle. By adopting two motors for each axle it is possible to run the armatures at twice the speed of one large motor. The one-hour rating of each motor

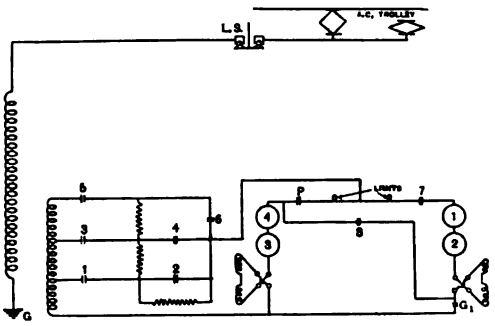

FIG. 318.—Connections for Single-Phase Working.

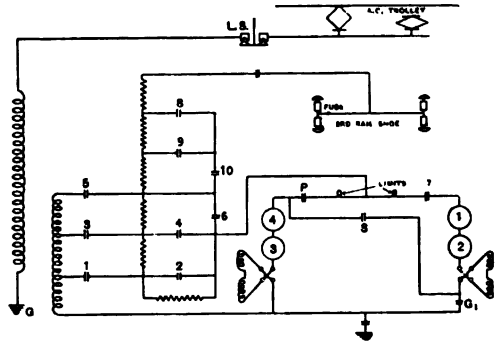

FIG. 319.—Connections for Continuous Current and Single-Phase Working.

is 170 h.p, and the continuous rating 145 h.p. Each pair of motors weighs 11,900 lb. The eight motors are lighter and cheaper than four motors of the same total output.

Forced ventilation has been adopted both for the motors and the transformers, and the air is driven through these by means of two electrically driven blowers, which are mounted underneath the cab between the trucks. The weight of all the electrical equipment is approximately 120,000 lb. As in the case of the other type of locomotive previously described, there are two pantograph current collectors, and a small collector is also fitted which is brought into use where the continuous current is collected from an overhead wire.

There are also shoes for collecting the continuous current from the third rail. These are lifted when the locomotives are working with alternating current. The overhead current collectors, sanding gear, etc., are all controlled by electro-magnetic valves, which are operated from push buttons.

There is not the least doubt that notwithstanding the ingenuity that has been exercised in the simplification of the alternating and continuous-current equipment of the locomotives and motor coaches, the use of the two kinds of current has proved a great nuisance. In a table given in Mr. Murray's paper previously referred to, it is shown that the simple alternating-current equipment of locomotives is 8,000 lb. lighter than the combined alternating and continuous-current equipment. Moreover, as indicated in the diagrams, Figs. 318 and 319, there are twice as many switches for the latter equipment as compared with the former where only alternating current is used. These facts point to the desirability of avoiding the use of a dual system.

THE NEW YORK, WESTCHESTER, AND BOSTON RAILWAY

THE New York, Westchester, and Boston line, the electrification of which was authorised at the same time as the Harlem River branch of the New York, New Haven, and Hartford Railway and the Hoosac Tunnel line, is at the time of writing the latest example of single-phase work in America. The overhead equipment is of particular interest, and calls for special attention. It is similar to that used on the Harlem branch of the New York, New Haven, and Hartford Railway. The work consisted of building a high-speed railway to deal with heavy traffic through twenty-one miles of practically undeveloped territory. Current is collected from 11,000-volt overhead wires, and the pressure is reduced to 250 volts for use on the trains. Each coach is equipped with two 175 h.p. motors. Power for the line is derived from the Cos Cob generating station of the New York, New Haven, and Hartford Railway, and it is purchased from this company on a flat rate basis. Connection with the line is made at the end of the New Rochelle branch, where it approaches the line of the New Haven Railway, and, notwithstanding that this point is sixteen miles away from the power station, the transmission loss is only 3 per cent. The pressure on the overhead conductor, it will be noted, is the same as that used on the New York, New Haven, and Hartford Railway. At New Rochelle four branches are taken from the main line feeders of the New York, New Haven, and Hartford Railway, and carried by the side of the rails on the catenary bridges to Columbus Avenue. Here two of the feeders are carried south along the section of the railway to the New York end, and the two remaining feeders along the branch to White Plains.

Circuit breakers are connected between these feeders and the overhead wire at New Rochelle and Columbus Avenue, and also at intermediate points approximately in the centre of both of the four-track section and the White Plains branch, but they do not operate on ordinary overload, as experience gained on the New Haven line has indicated that this is undesirable. But a control wire has been put into use which is connected with the overload relays at the power house. Unless this control wire is energised by these relays, none of the circuit breakers can open. Another novel feature is that the overload relays at the power house automatically insert resistance in the circuit prior to operating so that the rush of current is limited when a short circuit occurs. A short circuit does not cause any circuit breaker to open except the two immediately affected by the fault. In every case the line circuit breakers are placed on the anchor bridges. The feeders are also divided into sections by circuit breakers, the sections being cross-connected at the ends by a wire which extends across each anchor bridge.

The four-track section of the line extending from Harlem River to Columbus Avenue is equipped with a compound catenary system. The New Rochelle branch, on the other hand, is provided with the single catenary construction, in order that the relative merits of the two systems may be determined.

In the former case a $\frac{7}{8}$-in. steel stranded cable is carried over the top member

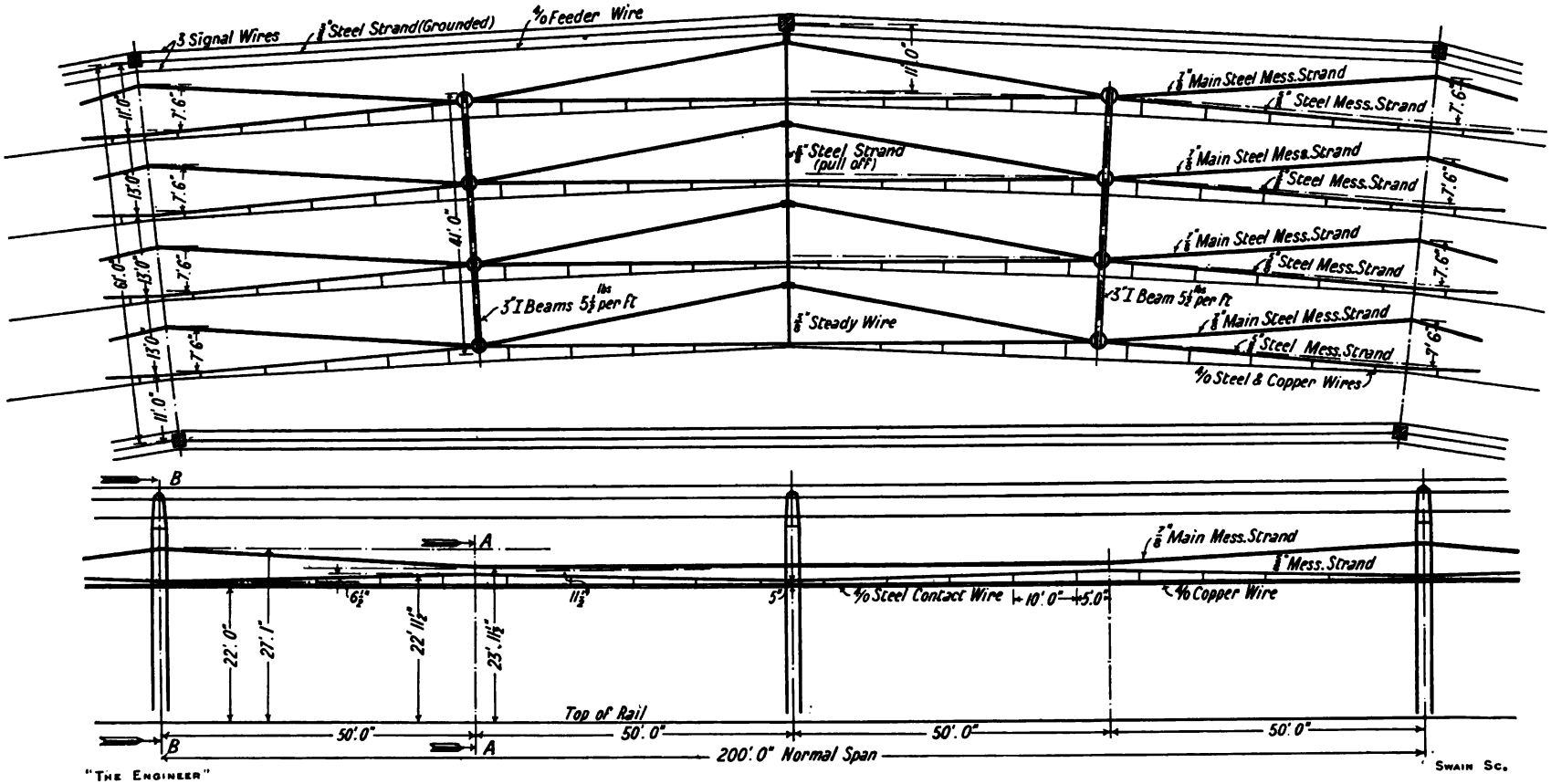

FIG. 320.—Details of Overhead Construction on Curves.

of the catenary bridges, and is fastened to them by cast iron clamps. These wires are, consequently, earthed. Between each pair of bridges there are two intermediate cross-bents composed of 3 in. I beams weighing 5½ lb. per foot, and these are clamped to each of the main supporting cables. From these intermediate cross-bents the track catenary supporting cables are hung, these being ⅝ in. stranded steel cables. These are insulated from the intermediate cross-bents by 110,000-volt insulators. The drawing, Fig. 320, shows the catenary construction on a 6 degrees curve. Fig. 321 is a section across the parts AA, and Fig. 322 a section across BB in Fig. 320. Fig. 323 shows the arrangement of a pull-off pole on a curve. Underneath the last-mentioned cables there is a No. 0000 grooved copper wire, which is supported by hangers spaced 10 ft. apart, and 2½ in. below this there is a No. 0000 steel grooved contact wire. These two latter wires are connected at 10 ft. intervals by clips spaced so as to come midway between the hangers from the track supporting strands. The method of spacing the clips and hangers gives a high degree of flexibility to the contact wire. At curves, however, the hangers are attached directly to the clips. These hangers, shown in Figs. 324 and 325, are composed of ½ in. steel rod threaded at one end and screwed into a hook-shaped casting which hangs over the track catenary supporting

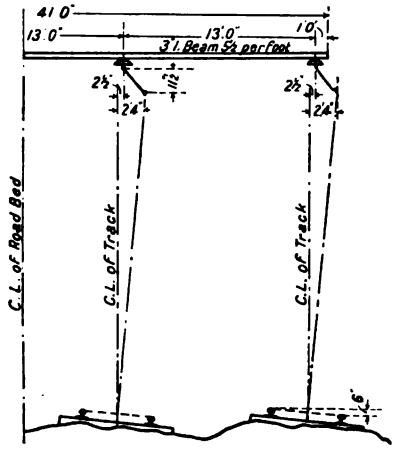

FIG. 321.—Section at AA, Fig. 320.

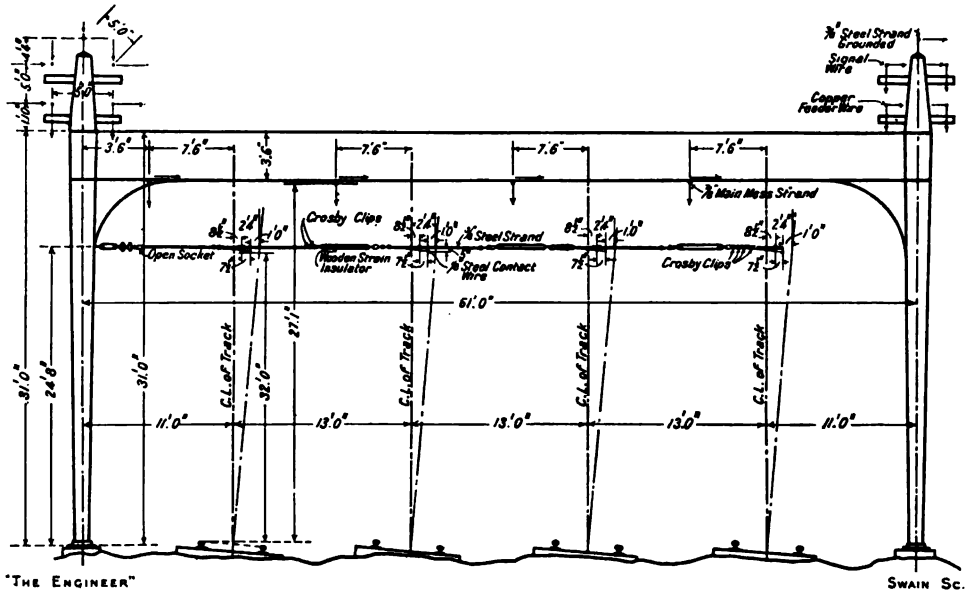

FIG. 322.—Section at BB, Fig. 320.

strand. The rod is screwed into the casting until it rests solidly against the supporting wire and holds the hanger securely in place.

On tangents the lower end of the ½ in. hanger rod is screwed into a casting the lower part of which forms a clamp which fits into the groove of the track conductor cable. This clamp is composed of two pieces of malleable iron and held firmly in

the groove of the cable by means of a ¼-in. screw, which passes through both pieces of the clamp. On curves where the hangers are directly fastened to the clips which hold the conductor and the contact wire together the lower part of the hanger is bent to the proper angle so the track conductor can take its proper position over the centre of the rails, and the end of the hanger passes horizontally through the clip. The horizontal end of the hanger is constructed with a shoulder, and the end is threaded to receive a ½-in. nut. The threaded end is passed through a hole in the clip, and the nut is tightened up until the clip grips the two wires. At turn-outs where two contact wires have to be brought together a special clip is used, which consists of three parts, one of which is placed between the two wires, the other two parts forming the outside of the clamp. All three parts are gripped firmly on the two wires by means of a ½-in. screw passing through them. These clips are approximately 6 in. long; there are two screws to each clip. The spacing of 10 ft. between the hangers and between the clips is maintained over the entire line. The bridges are spaced 300 ft. apart, but at curves and at some of the overhead highway crossings the distance between the bridges has been reduced.

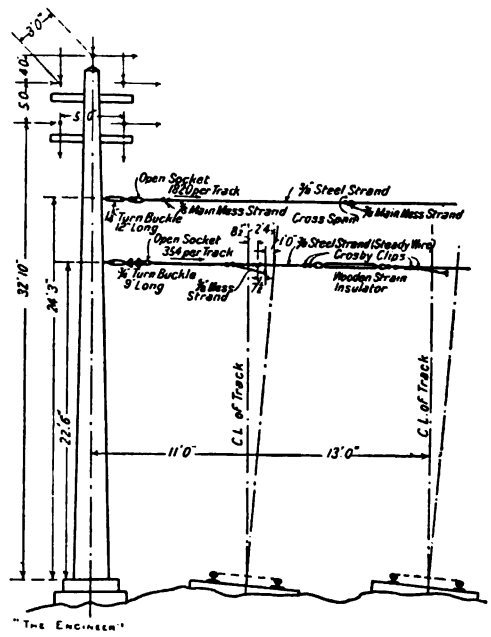

FIG. 323.—Pull-off Pole on Curve.

On curves up to 2 degrees the conductor and contact wires are made to take up the proper position with respect to the track by off-setting the points of support of the main supporting strands on top of the bridge. In the case of curves of over 2 degrees the catenary bridge spacing is reduced in accordance with the curvature to a minimum of 200 ft. On curves of over 4 degrees deflection pull-off poles are erected between the bridges and the main supporting strand is subjected to a side strain by means of ⅝-in. steel pull-off wires. On curves at points where the bridges are closer together than 100 yards the shorter span involves a decreased deflection of the main supporting cable in order to avoid unbalanced strain on the bridges. At these points bracket hangers composed of two pieces of angle iron set 45 degrees from the vertical are introduced between the main supporting strand and the intermediate cross bent to make up the space between them, as the contact wire is maintained at a constant elevation of 22 ft. above the rails, except at low bridges. The minimum height in these cases is approximately 17 ft.

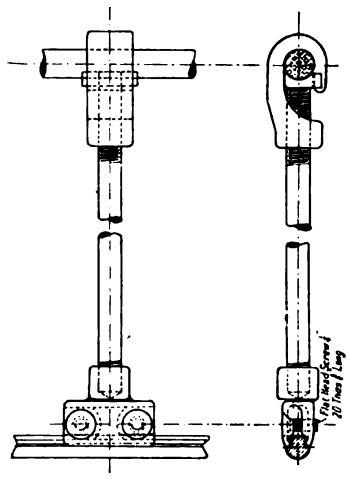

FIG. 324.—Straight Hanger.

The method of insulating adjoining sections of the line without causing a break in the circuit is shown in Fig. 326. It will be noted that a continuous surface

of live wire is exposed to the current collectors on the trains, but that the contact wires on each of the two adjoining sections at anchor bridges are isolated from each other by insulators and by a gap of 18 in. Fig. 327 gives details of a strain insulator, clips, etc., used at these anchor posts. It will be understood that the objection to introducing a dead gap in the contact wire is that damage is likely to result from the heavy arcs which are drawn off in breaking a high-voltage circuit.

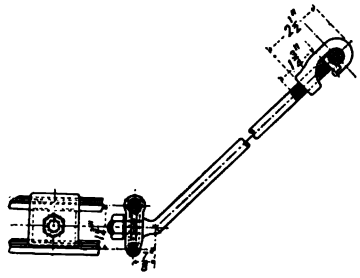

FIG. 325.—Bent Hanger.

At stations and at overhead bridges the wires are supported on insulators hung from I beams, which are clamped to the bottom of the bridge member by a short piece of angle iron.

As stated above, the New Rochelle branch has been equipped with single catenary overhead construction. The difference between the single catenary and the compound catenary system is that in the former case the main supporting cable and the intermediate cross-bents are eliminated. The catenary cable, which is composed of a $\frac{5}{8}$-in. steel stranded cable, is swung over the clear length between adjoining catenary bridges, and is hung from 110,000-volt insulators fastened to the under-side of the trusses.

The copper conductor and the grooved steel wire are hung from the catenary

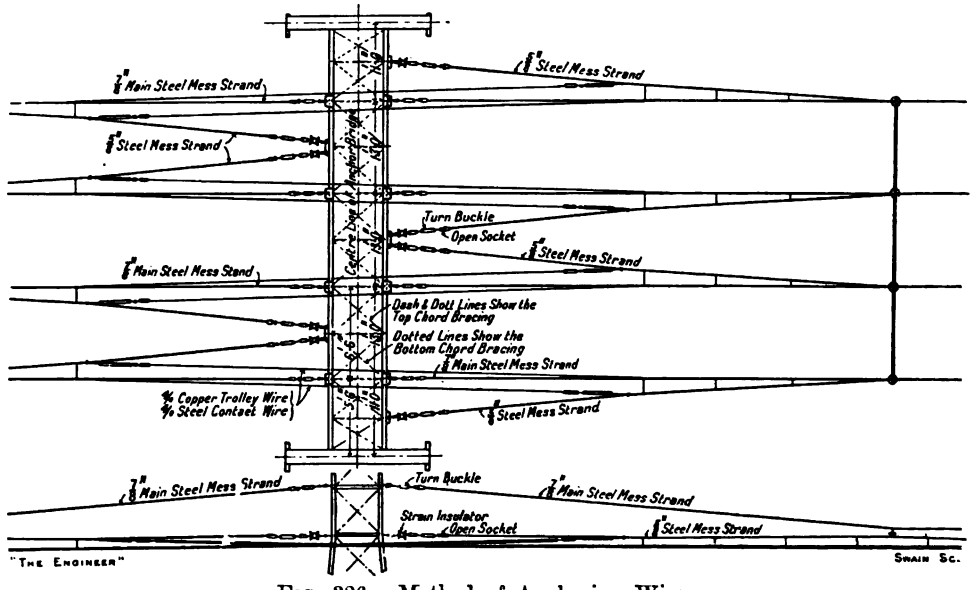

FIG. 326.—Method of Anchoring Wires.

with hangers and clips in exactly the same manner as in the compound catenary construction. The hangers are much longer at the points of support, since the catenary span is 300 ft. instead of 150 ft., with the compound type of construction. The bridge spacing for the single catenary is 300 ft. on straight tracks and about 200 ft. on the sharpest curves. Pull-off poles are used between the bridges on curves greater than 4 degrees.

All the bridges which carry the overhead wires are of steel, and they are supported on concrete foundations. The majority of the vertical posts are built

up of four-cornered angles and diagonal lattice work on all four sides made of flat steel bars set at an angle of 45 degrees and riveted together at their intersections. There are $\frac{3}{8}$-in. gusset plates at the bottom of the posts, and these are riveted to the corner angles, and the two sides which stand parallel to the track have 6 in. by 6 in. by $\frac{1}{2}$ in. angles riveted to them to form lugs for the anchor bolts. On the four-track section of the railway the posts measure parallel with the track 2 ft. lengthways both at the top and at the bottom, but the dimensions at right angles to the rails are 1 ft. $0\frac{1}{2}$ in. at the bottom and 2 ft. 2 in. at the top. The reason for this is that the point of greatest moment occurs at the top of the post, where it is joined to the bridge members which cross the track. The same design applies also to double track. Steel gusset plates are riveted to the two sides of the posts, and the cross-bridges are attached to these. For the four-track construction these bridges are composed of two trusses 3 ft. 6 in. deep. These trusses are tied together with a single lattice work of $2\frac{1}{2}$ in. by $\frac{1}{2}$ in. by $\frac{5}{16}$ in. angle iron at the top and bottom. Diagonal cross-frame supports between the two trusses are used every 13 ft. to prevent any tendency to buckle. Special precautions have been taken to ensure continuity of the service. When about to work on any line the wire is first isolated by the circuit breakers at each end of the section and then earthed by connecting it to the rails.

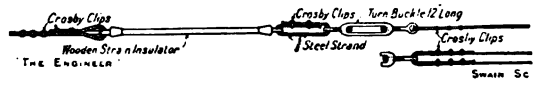

FIG. 327.—Details of Insulator Clip, etc.

THE SPOKANE AND INLAND EMPIRE RAILWAY

THE Spokane and Inland Empire Railway, a section of the Inland Empire system in Eastern Washington and Idaho, is a 6,600-volt single-phase 25-cycle line, and has been in operation since October, 1906. The other sections are the Coeur d'Alene and Spokane Railway, a fifty-eight mile 600-volt continuous-current inter-urban line, and the Spokane Traction Company's system, operating fifty-two miles of city street lines. The map of the railway has the shape of an inverted Y. The line runs south from Spokane with a junction at Spring Valley, forty miles distant. The eastern branch runs to Moscow, Idaho, and the western branch to Colfax, Washington. The right of way is the property of the company, with the exception of the streets of Spokane. Starting from the station in Spokane the first two and a half miles of the line are operated with 600-volt continuous current, whilst the remainder of the railway is electrified on the single-phase system. Two sets of rails have been laid on the first-mentioned section, whilst the remainder of the railway is constructed with a single track. On the single-phase section a single catenary overhead system has been adopted, and the wires are supported by bracket arms. The contact wire is of copper. After four years' service a piece of this wire which had been in use at a point approximately twelve miles from Spokane showed a wear of ·004 in.

The business of the company has grown rapidly, necessitating frequent additions to the rolling stock. At the end of 1911 there were five 72-ton goods locomotives, six 52-ton goods locomotives, four combination mail baggage and express motor coaches, seven baggage and smoking pilot motor coaches, four intermediate passenger coaches, one standard private coach, six trailers with observation compartments, one motor coach specially equipped for line maintenance work, two hundred and four box coaches, one hundred and fifty-eight flat coaches, eighteen ballast coaches, ten stock coaches, six refrigerator coaches, two steam shovels, one steam ditcher, and two steam shunting locomotives. Power is obtained from a hydro station situated on the Spokane River nine miles from Spokane. This station is owned by the Inland Empire Company and supplies current to the Spokane and Inland single-phase line, also to two 1,500-K.V.A. synchronous motor generator sets, which in turn supply part of the continuous current to the Spokane Traction Company and the Cœur d'Alene line, and approximately 1,000-K.V.A. used in various industrial works. Both these continuous current lines are operated for the most part with power purchased from the Washington Power Company under a contract which has several years to run, but upon its expiration the hydro plant will doubtless provide power for all the lines. The alternators in this station are of the three-phase type, and generate current at a pressure of 2,200 volts. This pressure, however, is raised to 60,000 volts, and current at this voltage is transmitted to Spokane over two transmission lines. During the initial operation of the Spokane and Inland Railway 60-cycle current was purchased, and this necessitated the provision of a frequency-changing station at Spokane. As the single-phase railway load is small in comparison with the capacity of the

generators at the hydro station, and as the distributing pressure in this territory is 60,000 volts and the periodicity 60 cycles, it was deemed advisable in developing the station to transmit the current at this pressure and periodicity. There are four units in this frequency-changing station.

Each consists of a 1,000 h.p. three-phase 4,000-volt 60-cycle induction motor, a 1,000-kw. single-phase 25-cycle 2,200-volt generator, and one 750-kw. 550-volt continuous-current generator, all mounted on a common bedplate. There are also two boosters which are used in conjunction with a 2,000-ampere-hour storage battery. The latter serves to equalise the load on the generating station. From this station current is supplied directly to the overhead conductor of the railway and to a 45,000-volt single-phase transmission line, which feeds various transformer sub-stations.

FIG. 328.—Goods Locomotive, Spokane and Inland Railway.

There are ten of these transformer sub-stations, nine of which are situated by the side of the railway and approximately twelve miles apart. The lines are sectionalised with circuit breakers fixed near each sub-station, so that each section is fed from two stations, except the southern end of the eastern division. This section is fed only by the trolley wire stretching from Palouse, Washington, to Moscow, Idaho. Under normal conditions the trolley wire is continuous from end to end. The sub-stations contain two or three 375-kilovolt-ampere single-phase 25-cycle 45,000 to 6,600-volt oil insulated self-cooled transformers. The ticket collectors act as sub-station attendants and use the transformer room as sleeping quarters. Each circuit is equipped with an electric alarm, which gives warning when a circuit breaker is opened.

There are two goods trains daily ; one runs to Moscow and the other to Colfax. A 72-ton locomotive is shown in Fig. 328. It is equipped with four 175 h.p. motors

of the forced ventilated type. Locomotives of this type can haul a 315-ton train at approximately twelve miles per hour on a 2 per cent. gradient. The maximum speed is twenty-seven miles per hour. Two locomotives are frequently used together. Fig. 329 shows a single-phase locomotive on the test track at Wilmerding, Pa. (it is equipped with four motors), and Fig. 330 a 49-ton locomotive, which, like the other engines, is built for alternating and continuous current operation. All these locomotives were built jointly by the American Westinghouse Company and the Baldwin Locomotive Works. Two of the 52-ton locomotives as used on this line will haul a 450-ton locomotive at approximately seventeen miles per hour on a 2 per cent. gradient. The maximum speed is thirty miles per hour.

All motor coaches of the passenger trains are equipped with four 100 h.p. geared motors. In this instance the motors are of the ordinary air-cooled type,

FIG. 329.—72-ton Locomotive, Inland Empire Railway.

and no forced ventilation is employed. For collecting the alternating current pantograph collectors are fitted, whilst ordinary pole trolley arms serve to collect the continuous current. The latter, however, have been sufficiently well insulated to collect the alternating current if desired. Eight trains run between Spokane and Freeman, a distance of nineteen miles. Two trains run between Spokane and Rosalia, a distance of forty-six miles. These are composed of two motor coaches. Six trains run between Spokane and Moscow, the length of this run being 90·4 miles. Of these six, two are made up of a combination mail and express motor coach, a pilot motor coach, and one trailer. The other four of the six Moscow trains are made up of a pilot motor coach and a trailer. The remaining six trains run between Spokane and Colfax, a distance of seventy-seven miles. Two of these trains are made up of a combination mail and express motor coach, a pilot motor coach, and one trailer. The other four are made up of a pilot motor coach and a trailer.

The winter of 1909–1910 was one of the most severe experienced in the vicinity of the Spokane and Inland Railway, and this was the only local line that maintained

FIG. 330.—49-Ton A. C. and D. C. Locomotive.

its regular service. Before the first train started its journey in the morning, there were frequently twelve inches of snow on the rails. But by simply using a snow plough the snow was cleared, and the longest delay over a period of three months was only twenty minutes.

THE ROCK ISLAND AND SOUTHERN RAILWAY.

THE fifty-two miles of electrified line on the Rock Island and Southern Railway between Rock Island and Monmouth, Illinois, constitute another fairly recent example of single-phase work in America. There is a single line all the way, and for a distance of twenty miles from Rock Island it follows the right of way of a branch of the Chicago, Rock Island and Pacific Railway. The remainder of the line passes over private right of way. Throughout its entire length the line is exceptionally free from severe gradients and sharp curves. At Monmouth, the southern terminus, where the coach sheds are situated, direct communication is made with Galesbury over another line operated by the same company. This is a 500-volt continuous-current line, eighteen miles long. Rock Island, the northern terminus, is connected to Moline and Davenport by city and local service, whilst Aledo and other intermediate points are reached by branches of the Chicago, Burlington and Quincy and the Chicago, Rock Island and Pacific Railway.

The power-house is situated close to a coal mine at about the middle of the line. Two 1,000 kilovolt-ampere turbo-generators provide current at 2,300 volts, and at a periodicity of 25 cycles per second. The pressure, however, is increased to 11,000 volts, and is fed directly to the trolley wire at the power-house. The overhead construction is of the single catenary type. The drop in voltage at the end of the line under the worst conditions is so small that no other feeders have been put into use. In the first instance the rolling stock consisted of six passenger coaches, one express and local goods coach, and one slow-speed goods locomotive for heavy goods traffic. The passenger coaches each weigh 52·5 tons without load, and they are 62 ft. long. One of the motor coaches is shown in Fig. 331.

Each coach is equipped with four 100 h.p. single-phase motors, an oil-insulated self-cooled auto-transformer, and two pneumatically operated current collectors. Also the usual control gear with contactors operated on the Westinghouse principle which has already been described. It will be remembered that this company uses electro-pneumatically operated contactors, the control current for which is derived from a storage battery and small motor generators. The motor gear is mounted directly on the axle of the truck wheels, which are 37 in. in diameter, and the motor frame is spring suspended from the truck bolster. Eight tappings are brought out from the transformer for controlling the speed of the motors. The air compressor and motor generator set are operated from separate low voltage tappings. The main circuit connections and the order in which the switches are closed for acceleration are shown in Fig. 332. The motors are connected in pairs, and two in each group are permanently connected in series. Thus, the voltage taken from the auto-transformer is double that required for a single motor, and the amount of current to be handled by the switching apparatus is thereby decreased.

Four tappings from the auto-transformer feed two preventive coils, as shown in Fig. 332, and the voltages are equalised at the middle point of each coil to an average between their values at the transformer. The voltages derived from the respective

preventive coils are equalised in a third preventive coil, and the resultant voltage derived from the tappings is then applied to the motors through the main switches. The scheme will readily be understood from an inspection of the diagram, Fig. 332. When the controller handle is turned to the first notch, only two of the transformer

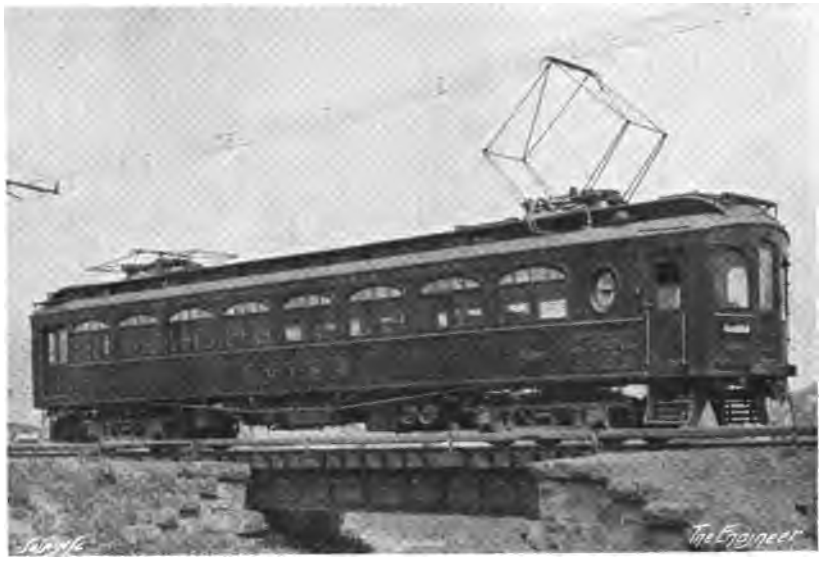

FIG. 331.—Passenger Motor Coach, Rock Island and Southern Railway.

switches are closed, giving a low starting voltage. The impressed pressure in the two motors in series varies from 210 volts with the controller handle in the second position to 460 volts with it in the sixth position. To prevent the motor armatures attaining abnormal speeds when a train is running down-hill a relay is fitted which cuts off the current at a predetermined speed. The relay consists

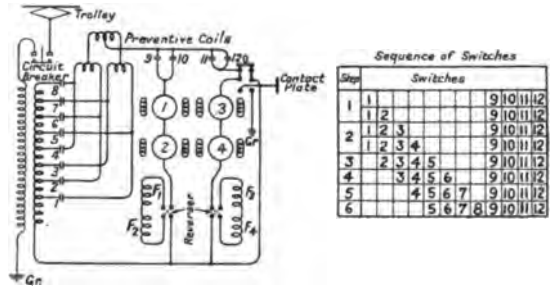

FIG. 332.—Motor Coach Connections.

of two coils, the cores of which are attached to a rocker which carries a contact disc. One coil is energised through a series transformer by the current in the motor lead, and the other by the voltage across one motor armature.

Normally the relay disc is held away from its contacts by the unbalanced weight of two relay cores, but when the motor accelerates to a speed at which the voltage across the armature overbalances the decreasing current passing through the motor, the relay disc lifts, thus completing a circuit which serves to close the control circuit

of an auxiliary relay, which in turn operates on the control circuit of the main motor switches. The auxiliary relay is operated from the battery circuit, and it remains open till the master controller is returned to the off position.

A switch and contact plate are provided for the purpose of shifting the coaches in and out of the sheds without drawing current from the high voltage overhead wiring.

By placing the double pole switch in the opposite position to that shown in the top right-hand corner of Fig. 332 and by applying a low voltage to the contact plate two of the motors are brought into use for moving the coaches at slow speeds. The current collectors are raised and lowered by push buttons embodied in the main controllers, and the button which lowers the collector also opens the circuit breaker, so that no arc can be formed between the collector and overhead wire. Express and local goods service is handled by coaches geared for the same speed as the passenger coaches.

THE HOOSAC TUNNEL RAILWAY.

WHEN we consider the advantages of electrical working in tunnels it is not at all surprising that trains running through the longest tunnel in the United States are worked with electricity. This is the Hoosac Tunnel, which is 25,081 ft. long and pierces the mountain range between the Hoosic and Deerfield rivers. Fig. 333 is a map showing its situation, and Fig. 334 a plan and profile of the tunnel. In 1851 the work of constructing this tunnel was commenced and the first steam train passed through it on February 9th, 1875. The tunnel is straight and two tracks are laid from end to end. Where the rock is soft it is lined with brick, but for the greater part the walls are bare rock. To drain off the large quantity of water which accumulates the tunnel has been constructed so that there are gradients of 26·4 ft. to the mile from each entrance to a short level stretch in the centre, at which point a shaft extends to the top of the mountains for ventilation. Altogether the scheme includes the electrification of the yards at North Adams, about

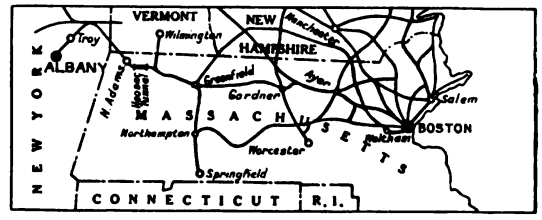

FIG. 333.—Map showing Position of Hoosac Tunnel.

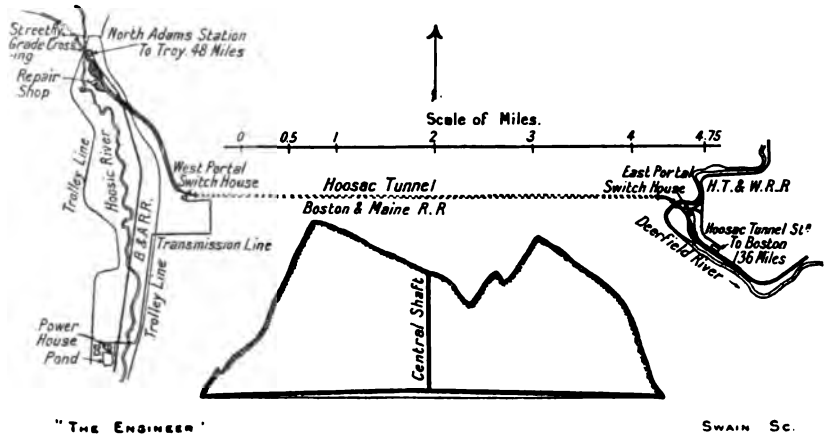

FIG. 334.—Plan and Profile of Hoosac Tunnel.

two miles of main line between North Adams and the west portal of the tunnel, where the gradient is about ·75 per cent., then 4·75 miles through tunnel, and the yards at the east portal, including three-quarters of a mile of main line having a gradient of about ·5 to ·7 per cent. In all 21·31 miles of single track are electrified.

Since the traffic in the tunnel is exceedingly heavy, it will readily be appreciated that the steam locomotives made travelling very unpleasant, but when electrical working was started the conditions were greatly improved. In fact, in hot weather

travelling in the tunnel becomes a pleasure, and passenger trains pass through with the windows open. Moreover, when the tunnel was electrified automatic block signalling was brought into use, and the capacity was increased threefold, since three trains on the same track can be in the tunnel at once. The system of operation is to couple an electric locomotive to the front of the steam engine and to pull the complete train through the tunnel. During the journey the fires of the steam locomotive are kept still, so as to avoid filling the tunnel with smoke and gases. That the system is successful so far as the elimination of smoke in the tunnel is concerned is evident from the fact that it is usually possible to see right through the ventilating shaft—a distance of 2·37 miles.

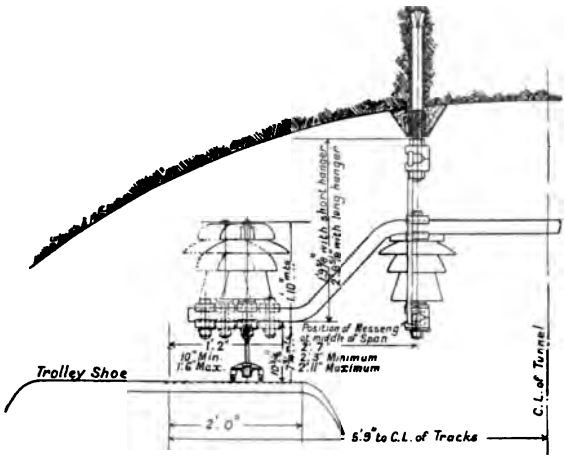

FIG. 335.—Supports for Wire in Tunnel.

In many respects the overhead equipment corresponds to that used on the New York, New Haven, and Hartford Railway between Woodlawn, New York, and Stamford, Conn. From the crown of the tunnel brackets are suspended as shown in Fig. 335. Four insulators, each capable of resisting a pressure of 150,000 volts, are fixed on these brackets, and two serve for each track. The arrangement is such that two insulators are in series, thus giving a combined

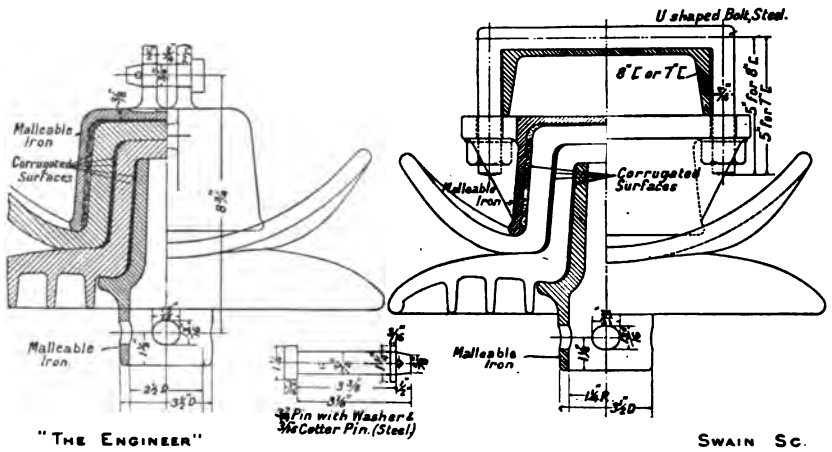

FIG. 336.—Contact Line Insulators.

dia-electric strength which will enable them to resist 300,000 volts. Since the voltage on the overhead conductor is 11,000 volts, the insulation employed might appear excessive, but having regard to the fact that the cost per insulator was only about 4*s*. 2*d*. more than the price of one of one-eighth the resistance, and bearing in mind also that a long tunnel is not at all a desirable place for a train to be brought to a standstill, the use of these more expensive insulators was no doubt justifiable.

There are 1,000 insulators in the tunnel, so that approximately £200 has been spent to secure eight times the usual protection. At the approaches to the tunnels

insulators of the types shown in Fig. 336 are used. In this case an extra expenditure of 2*s.* 1*d.* per insulator secured practically three times the protection as compared

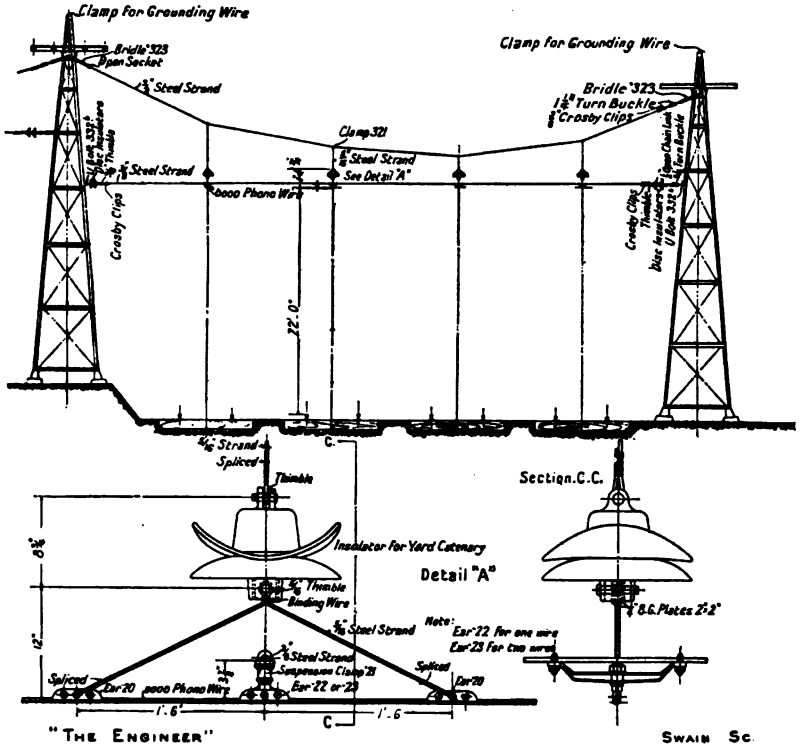

Fig. 337.—Overhead Construction in Yards.

with that given by an ordinary 40,000-volt insulator. In Figs. 337 to 341 some further details of the overhead construction are given, these illustrations having

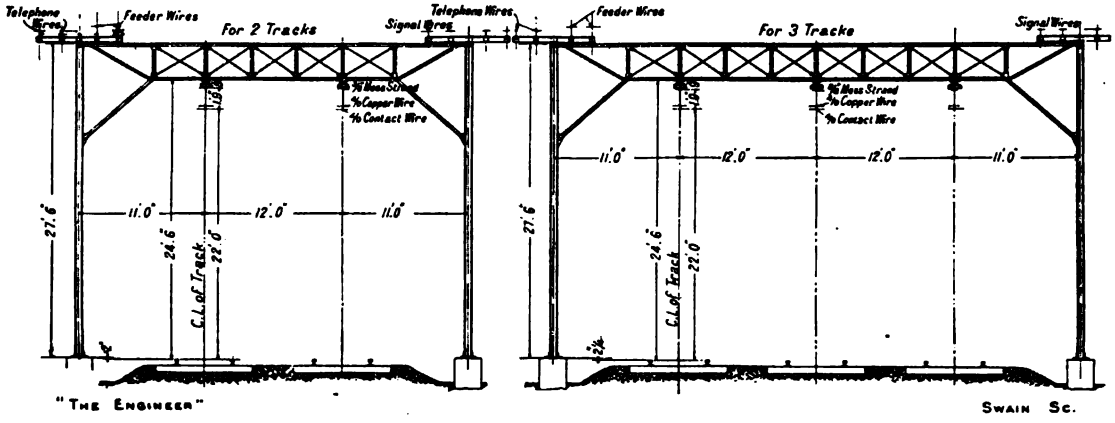

Fig. 338.—Construction on Open Track.

been reproduced from Mr. W. S. Murray's paper on "Trunk Line Electrification," referred to elsewhere. Fig. 337 shows the overhead yard construction for the Hoosac Tunnel scheme, and Fig. 338 some other examples of construction as used

on the open track. Fig. 339 shows the method of connecting the feeders with the contact lines, and Fig. 340 the details of one of the feeder insulators; Fig. 341 illustrates the details of a double catenary hanger as used in the tunnel. It will be perceived that outside the tunnel two different systems of supporting the line have been adopted. For two and three track sections on the main line the supporting bridges are built-up trusses of the type shown in Fig. 338. They are formed of 7 in. or 8 in. channel top and bottom chords with light angle posts and double diagonal rod braces in each panel.

These bridges are supported at each end by A-shaped frame towers formed of two 8 in. channels braced with light angles, the plane of these towers being parallel to the centre line of the tracks. In the yards where more than three tracks are

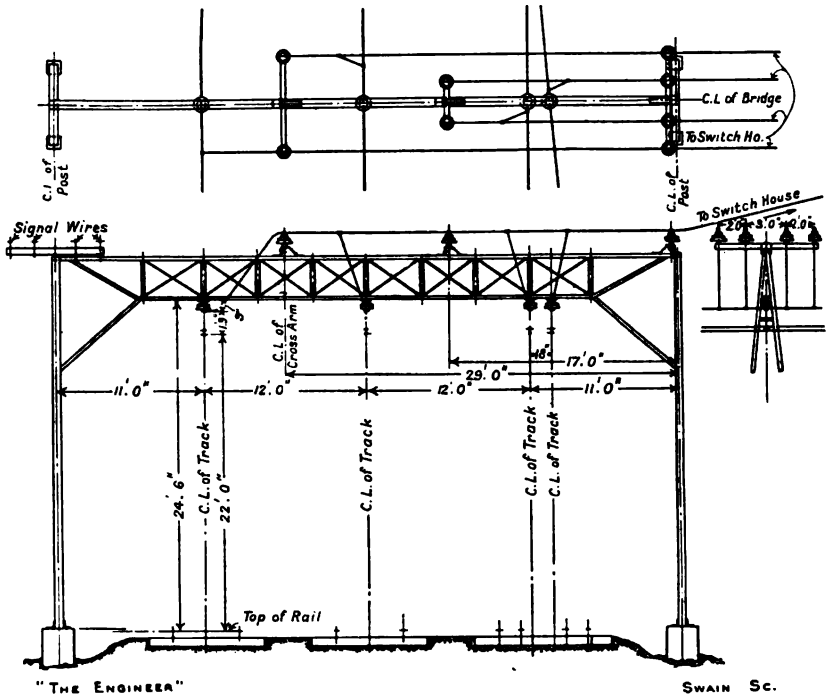

FIG. 339.—Method of Connecting Feeders to Contact Wires.

equipped with overhead wires cross catenary span wires are suspended from the apex of A-shaped frame steel towers built of 8 in. channels with their sides in a plane at right angles to the track. This construction is shown in Fig. 337. The catenary cable insulators are suspended from these steel cross catenary cables by stranded steel wires. Each tower is earthed by a cable clamped to the apex. The anchor bridges are box trusses supported on heavy A frame towers with latticed sides stiffened with double diagonal braces. The wiring of the railway is cut up into twelve sections.

An interesting feature of the overhead wiring is the crossing of the double 11,000-volt trolley wire over the 600-volt wires of the Berkshire Street Railway to the west of North Adams Station. The 600-volt wires are sectionalised with wooden insulators 8 ft. long on each side of the crossing and are carried over the crossing under an inverted 5 in. channel which is supported by stranded cable span wires. This channel iron is on the same plane as the 11,000-volt alternating current wires, but is insulated from them by section insulators. Under normal conditions the

continuous-current wires in this crossing section do not carry current. But on the north side of the crossing a feeder is connected to the 600-volt trolley wire and carried to a switch on top of a wooden pole.

When this is closed by pushing a rod in an upward direction, 600-volt continuous current is fed on to the crossing channel and trolley wire so as to permit a street coach to pass over the crossing. When the rod is released the switch opens by gravity, and by making another contact earths the channel iron and the continuous-current trolley wire. The section insulators in the 600-volt trolley wire are earthed at the centre of their length, so that in the case of breakdown of any of the 11,000-volt section insulators the 11,000-volt current cannot leak past them.

The catenary cable inside the tunnel is composed of $\frac{5}{8}$ in. stranded steel cable, which supports a No. 0000 grooved conductor by rigid hangers of varying lengths at intervals of 10 ft. The contact wire, which is a No. 0000 grooved wire, is carried 1·75 in. below the copper conductor by double clips attached in the centre of the 10-ft. spans between the hangers. On curves the conductor and contact wires are both suspended from the catenary cable by inclined hangers having double clamps.

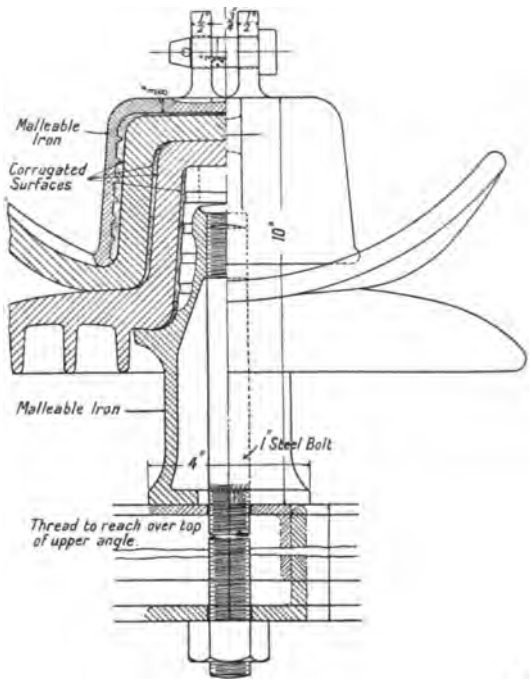

FIG. 340.—Feeder Insulator.

Owing to the small clearance and the great amount of moisture present, the problem of properly insulating the 11,000-volt overhead wires proved difficult. The supports, which are 100 ft. apart, consist of U-shaped brackets, as shown in Fig. 341, which are parallel to the track and are held in place by 1·25 in. wrought-iron bolts extending 18 in. into the rock or brick arch. These bolts are split at the upper end and hammered in together with a wedge, but prior to setting the bolts, the holes were filled with cement, and this rather than the wedges is relied upon to hold the bolts in place. The U-pieces support a bracket of the type shown in Fig. 335 by means of two 150,000-volt triple-petticoat porcelain insulators, and these brackets, which extend across the track, support the catenary cable by other 150,000-volt insulators. Owing to the limited clearance in the tunnel the two contact wires are fixed only 15 ft. 6 in. above the rails. For the same reason the catenary cables are supported 14 in. inside the centre line of the track. This gives a minimum clearance of 12 in. between the catenary cable and the roof of the tunnel. All parts of the tunnel hangers are made of bronze.

It is easy to imagine that the difficulties encountered in erecting the overhead equipment in the tunnels without seriously interfering with the traffic must have been considerable. But perhaps this will be better understood when it is stated that when the steam trains were at work it cost no less than 10*s*. to replace a sleeper owing to the fact that the men could only work in the tunnel for a couple of hours a day, and it was a common occurrence to have men brought out unconscious owing to the

bad air. To reduce the amount of smoke during the work of construction the railway company purchased four large Mallet compound oil-burning engines. The work was done from two specially constructed trains, each consisting of an oil-burning locomotive, two locomotive tenders, a box car containing blacksmiths' forges and anvils, an air compressor car, thirteen platform cars on which were built working platforms raised 11 ft. above the rails, a coach fitted up as a dining car, and a goods caboose.

The train was fitted with pipes for the supply of compressed air, and lighted throughout with electricity. On the floor of every third platform a wooden compartment was built, into which the men retreated during the passage of a train through the tunnel. An air valve was provided inside these compartments, which, when partially opened, created sufficient pressure to keep out the smoke and gases and to provide fresh air for the men to breathe. The constructional work in the tunnel included the drilling of 1,000 holes 2·5 in. in diameter and 18 in. deep in the roof of the tunnel for the catenary hangers; 1,500 holes 1·75 in. in diameter and 6 in. deep in the side walls for telephone and signal cable hangers; the drilling and blasting of the rock roof of the tunnel to obtain the necessary clearance in various places; and the erection of the overhead wires. To improve the working conditions, a large fan was erected at the top of the central ventilating shaft.

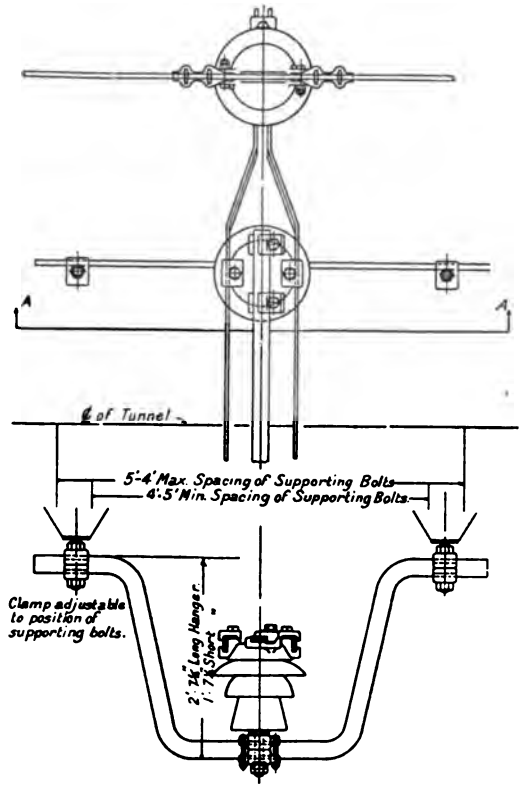
℄ of Tunnel
5'-4" Max. Spacing of Supporting Bolts
4'-5" Min. Spacing of Supporting Bolts
Clamp adjustable to position of supporting bolts.
2'-7½" Long Hanger
1'-7½" Short

FIG. 341.—Hanger as used in Tunnel.

The power-house is at Zylonite, about 2·5 miles south of the west portal of the tunnel. It is situated near the old power-house of the Berkshire Street Railway. The engine-room contains two main generating units, each consisting of a 11,000-volt three-phase 3,750-kilovolt-ampere (single-phase rating) generator, coupled to a double-flow turbine. It will be understood that one phase of each generator is used for the railway.

The current is transmitted at 11,000 volts from the power-house to a switch-house at the west portal of the tunnel, over a double transmission line 2·42 miles long. Along the straight part of the line the towers which carry the wires are formed of two 8-in. channels connected together by angle-iron braces and diagonals, and tied together by a cross-piece at the top. These towers carry two angle-iron cross arms, and are supported on two foundation piers set at right angles to the direction of the line. They are spaced about 300 ft. apart on the level.

The transmission line consists of five stranded copper cables, two of which carry current for working the trains, and are suspended from the cross-arms at one side of tower, while power and control wires are suspended in a similar manner from the other side. The contact wire bus-bar in the power-house

furnishes power for the electric locomotive load and a control bar supplies power to operate the circuit breakers, which control the various sections of the track, at the west portal of the tunnel and at the repair shop. The cross-tie at the top of the tower carries an insulator to support the earth wire, which also serves as a guard wire for protecting the transmission line against lightning. The line terminates at the switch-house at the west portal of the tunnel, this switch-house controlling the whole system, for the switch-houses at the east portal and at the repair shop are not connected to the transmission line, but are fed through the trolley wires of one or both main tracks. Therefore, so long as current is on either one of the main trolley wires the remainder of the system can be operated. The same towers which carry the transmission line also carry two telephone wires supported on one of the cross braces between the channels, about 10 ft. below the high-tension wires. Noise caused by induction on the telephone line is prevented by frequent transposition of the wires. This effect is also reduced by transformers having a ratio of 1 to 1. Static charges are dealt with by impedance coils, the centre point of which is earthed.

Coming now to the electric locomotives, these were built jointly by the Baldwin and American Westinghouse companies. Three of the engines are primarily intended for goods service, and are capable of developing a maximum tractive effort of 67,000 lb., and are designed for a maximum speed of thirty miles per hour. The others are intended for passenger and light goods traffic, and exert a maximum tractive effort of 40,000 lb. The maximum speed is fifty miles per hour. All the locomotives are identical with the exception of the gear ratio. By changing the gears it would be possible to change a passenger locomotive to a goods engine and *vice versâ*. Each engine weighs 130 tons, 96 tons of which are on the drivers. They are 48 ft. long between the couplers, and the total wheel base is 38 ft. 6 in.

The locomotives have two articulated trucks, each truck having two pairs of 63 in. drivers, a 7 ft. rigid wheel base, and a pair of radial pony wheels 42 in. in diameter. The trucks are of very heavy and substantial construction. They are connected by a heavy draw-bar. The cab is supported by four loaded friction plates on each truck. One truck centre-pin has longitudinal play relative to the cab, thus relieving the latter of pulling and bumping stresses. The power is derived from four 375 h.p. single-phase motors directly mounted over the driving axles, and bolted to the frame. The power is transmitted from the motor by two flexible gears, which divide the load equally and prevent shocks on the gear teeth. These gears drive a quill surrounding the axles with 1·5 in. clearance, and run in bearings in the motor frame. The quill in turn is connected to the wheels by a system of long helical springs, which allow the wheel to follow any inequalities in the track without affecting the motor.

The electrical equipment consists of the following parts: Four 375 h.p. single-phase motors already referred to, one air blast auto-transformer, two 11,000-volt pneumatically-operated current collectors, one 11,000-volt oil circuit breaker, three preventive coils, four groups of pneumatically-operated contactor switches, two 10 h.p. motors for driving the compressors, one pilot governor operating a compressor switch, two 7·5 h.p. blower motors, two 20-volt storage batteries for operating the electro-magnet valves, one motor generator set for charging the batteries, one speed limit relay, two master controllers, two temperature indicators for showing the temperature of the main motors, and the necessary control circuits for multiple unit operation.

Twelve tappings are brought out from the auto-transformer for controlling the motors. The overload tripping mechanism of the oil circuit-breaker operates in conjunction with a dashpot, which latter prevents the circuit-breaker opening as a

result of momentary surges in the high-tension line. This circuit-breaker is closed by an air cylinder and opened by a spring. Each of the contactor switches is fitted with a magnetic blow-out. The main circuit connections and the order in which the switches are closed for starting the locomotives are shown in Fig. 342. All the main

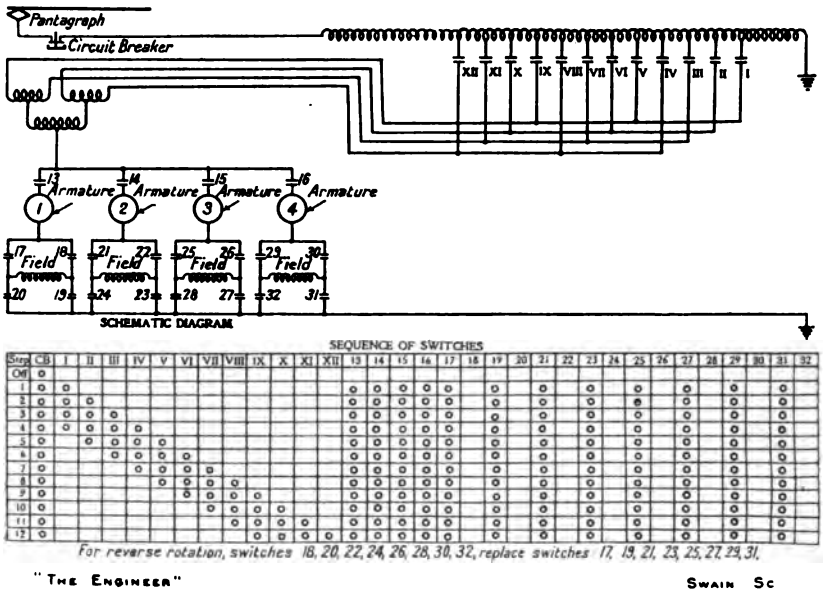
Pantograph
Circuit Breaker
XII XI X IX VIII VII VI V IV III II I
13 Armature 14 Armature 15 Armature 16 Armature
1 2 3 4
17 Field 18
21 Field 22
25 Field 26
29 Field 30
20 19
24 23
28 27
32 31
SCHEMATIC DIAGRAM
SEQUENCE OF SWITCHES
Step CB I II III IV V VI VII VIII IX X XI XII 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Off
For reverse rotation, switches 18, 20, 22, 24, 26, 28, 30, 32, replace switches 17, 19, 21, 23, 25, 27, 29, 31.
"The Engineer"
Swain Sc

Fig. 342.—Locomotive Motor Connections.

motors are connected in parallel, and any machine may be cut out by operating a switch. An overspeed relay is provided, which automatically shuts off the current from the motors at a predetermined maximum speed. This prevents the locomotives attaining a speed which will damage the motor armatures, but it does not prevent their attaining a high speed on down gradients.

THE ST. CLAIR TUNNEL RAILWAY.

ANOTHER interesting example of the use of single-phase current for working trains underground is to be found in the St, Clair Tunnel, under the St. Clair River, between Port Huron, Mich., and Sarnia, Ont., on the Grand Trunk Railway. As in the case of the Hoosac Tunnel, a desire to increase the traffic was the primary object in electrifying the line. When hauling a 700-ton train difficulty was often experienced in getting steam locomotives to reach the summits of the gradients at the ends of the tunnel. But the single-phase locomotives are capable of hauling a 1,000-ton train up the 2 per cent. gradients at ten miles per hour. Moreover, they have afforded a means of overcoming the difficulties previously experienced in connection with the ventilation of the tunnel. Electrification was the logical solution of the problem. Fig. 343 is a map showing the course of the St. Clair Tunnel. A profile of the tunnel is shown in the lower part of this illustration. The St. Clair River is deep at Port

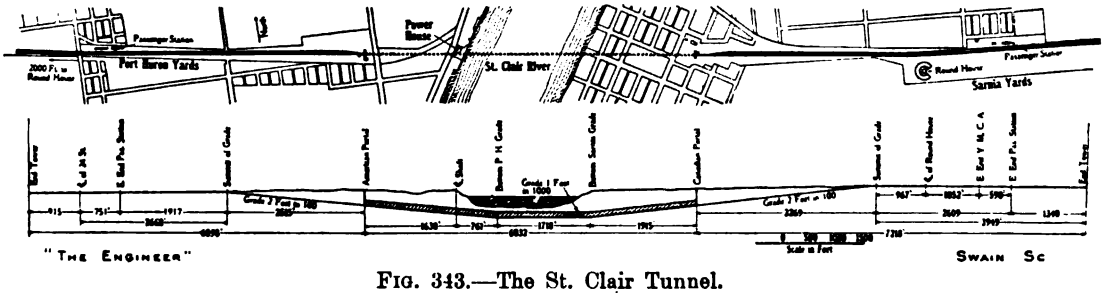

FIG. 343.—The St. Clair Tunnel.

Huron, and the level portion of the tunnel is 100 ft. below the level of the yards; hence the necessity for a portion of line being laid on a 2 per cent. gradient. The level portion of the tunnel connecting the two gradients is a third of a mile long.

The double lines on the gradients merge into single tracks just outside the tunnel at both ends. The shell of the tunnel is 20 ft. in diameter, and is made up of cast iron rings composed of thirteen segments 18 in. wide. There are some four thousand of these rings in the tunnel shell. Steam service was commenced in 1890, prior to which time the connecting link between the American and Canadian Grand Trunk systems was a ferry car. Heavy steam engines specially built for the tunnel service used to haul the trains through the tunnel, and they were fired with hard coal. This eliminated smoke, but not the gases of combustion nor the exhaust steam. The time required to traverse the tunnel was about four minutes. Although the trip was anything but enjoyable, it was not necessarily dangerous.

The power station is situated on the Port Huron bank of the St. Clair River at a point almost directly over the tunnel. It contains two 1,250-kw., three-phase 25-cycle, 3,300-volt turbo-generators. Either of these is capable of handling the maximum demand on the station. Just outside the power station is a vertical shaft which leads to the tunnel. A reinforced duct has been built in this shaft, and all the feeders pass from this duct through holes into the tunnel. The overhead

wiring is divided into sections, but normally the wires are continuous from the Port Huron yards through the tunnel to the Sarnia yards, a distance of 3·7 miles. In the yards a single catenary system is used. The supporting bridges are 250 ft. apart. In the open the contact wire is 22 ft. above the track. A modified catenary system is employed in the tunnel. There are two parallel catenary wires and two parallel contact wires. The former are supported on parallel insulators spaced at intervals of 12 ft. The supporting cables carry the double droppers, which are also spaced

FIG. 344.—Locomotive, St. Clair Tunnel Railway.

at a distance of 12 ft., but situated 3 ft. from the middle of the catenary span. The clearance between the supporting cables and the shell of the tunnel is 3 in.

The contact wires are 6 in. below the supporting cable, giving a minimum clearance of 15 ft. 5 in. between the overhead conductors and the rail. Owing to the fact that the tunnel is damp, some doubt existed in the minds of the engineers as to the advisability of adopting a pressure of 3,300 volts on the contact wire, and especially as this is only a few inches distant from the shell of the tunnel. Experience, however, has shown these fears to be groundless.

One of the locomotives as used on the St. Clair Tunnel Railway is shown in Fig. 344. These engines weigh 66 tons, and they are generally used in pairs. Two locomotives are able to draw a 1,000-ton train through the tunnel and up the 2 per cent. gradient, the draw-bar pull being 50,000 lb. The approaches to the gradients are about 4,000 ft. long. Each 2 per cent. gradient is about one mile long, and a one-tenth per cent. gradient at the middle of the tunnel is one-third of a mile

long. Should it become necessary to stop the trains on the 2 per cent. gradient the locomotives can accelerate the train up to eleven miles per hour. The maximum safe speed of the locomotive is thirty miles per hour.

Each locomotive has three pairs of driving wheels, 62 in. in diameter. The driving equipment consists of three 250 h.p. single-phase motors geared to the three driving axles. These motors are of the ten-pole compensated type and are designed to operate at a normal pressure of 235 volts and at a periodicity of 25 cycles per second. The motors are connected in parallel, and are so arranged that one or two machines can be disconnected if desired. Forced ventilation is used, and the blower which supplies the air under pressure also serves for the main auto-transformer. With forced ventilation the continuous rating of the motors is 750 amperes at 235 volts. Under these conditions two locomotives can pull a 2,500-ton train at a constant speed of fifteen and a half miles per hour for any desired length of time on a straight level track.

Upon completion each locomotive underwent a thorough test on the Interworks Railway at East Pittsburg. By means of a dynamometer the draw-bar pull exerted under various conditions was accurately measured. By setting the brakes on the train and keeping the locomotive brakes released a draw-bar pull of 45,000 lb. was obtained repeatedly by a single locomotive on clean, dry rails without sand. Tests were also made to ascertain the ability of the locomotive to start and accelerate trains of various weights and to find the capacity of the motors in continuous service. All the tests gave very satisfactory results. It should be mentioned that these tests were made in 1908, and it is probable that even better results could be obtained with more modern equipment. Fig. 345 shows the results of a test made on a locomotive designated No. 1305, accelerating a trailing load of 500 tons on a slight gradient on the Interworks Railway. The upper set of curves show the line kilowatts, line volts, and line amperes, whilst the lower curves show the motor amperes, motor kilowatts, motor volts, draw-bar pull, and speed. The gear ratio is 16 : 85, the diameter of the wheels 62 in., weight of locomotive and coaches 565·7 tons, maximum speed 16·5 miles per hour.

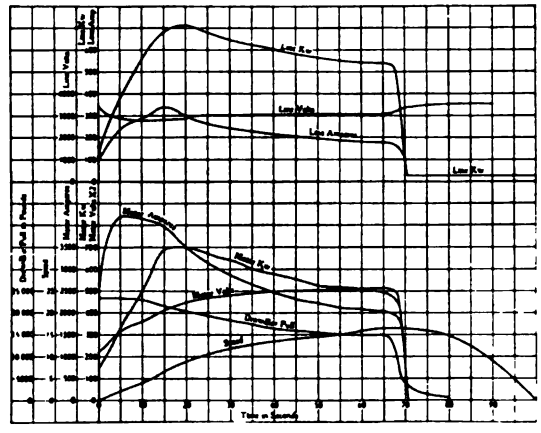

FIG. 345.—Acceleration Tests of Locomotive.

As the test run from which these curves were derived was made on an up gradient there was practically no coasting, hence the watt-hours per ton-mile are somewhat high. The results of a test made in actual service with two locomotives drawing a 900-ton train through the tunnel are shown in Fig. 346. The motor amperes, motor kilowatts, and motor volts have been plotted, and direct comparison of the curves can be made with reference to the conditions as given on the profile.

In addition to the motors the electrical equipment of each locomotive consists of a 3,300-volt transformer, three preventive coils, a line relay, three groups of contactor switches, two master controllers, two small storage batteries, and a small motor generator set. The transformer is connected to the current collector by means of a high-tension cable and the current passes through an oil circuit breaker

provided with a no-voltage release protective relay. Should a locomotive leave the rails and the frame become more or less insulated from earth this relay would cause the circuit breaker to open and to remain open till the earth connection had been re-established. There are three groups of contactors on each locomotive, two of which control the voltage supplied to the motors, whilst the third group serves for reversing the motors.

Each set of main contactors consists of ten electro-magnetically operated switches; the function of these is, of course, to connect the motors to the various tappings on the auto-transformer. There are four reversing contactors to each motor, so that in all there are twelve reversing contactors. A master controller is fixed at each end of the locomotive, and each has two interlocking handles—one for ordinary control purposes and the other for reversing. The master controller operates the various contactors by current from the 20-volt storage battery, and has seventeen running notches and three so-called switching notches. The latter are only used for running the locomotives without load at slow speed, as when passing over points in the yards. The circuit breakers are set to open when the low-tension current taken by the motors exceeds 4,500 amperes. Press buttons are provided for operating the pneumatic bell ringer, pneumatic sanding gear, the re-setting device of the circuit breaker, and the current collector. Foot pedals are also provided for operating the bell and sanding gear. Two or more locomotives may be operated as one unit from any controller. The air brake is of the Westinghouse Company's standard type, and there is an independent valve at each end of the locomotive.

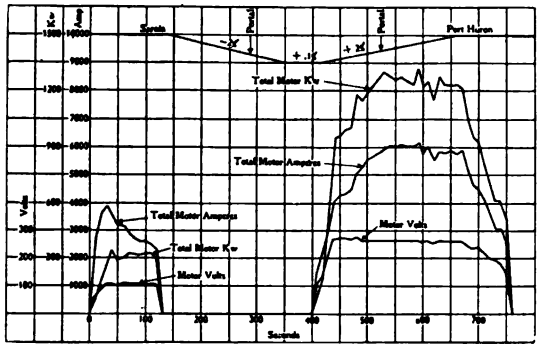

FIG 346.—Acceleration Tests of Locomotive.

The open cut of the American approach to the tunnel comprises some ten acres of land. This area drains towards the entrance to the tunnel, at which point a pumping station has been built. The pumping equipment consists of two motor-driven centrifugal pumps, each having a capacity of 4,000 gallons of water per minute. There is also a motor-driven centrifugal pump having a capacity of 150 gallons per minute. A similar pumping plant is situated at the Canadian entrance, but as the area of the open cut at this end is somewhat greater than that at the opposite end each pump in this station has a capacity of 5,500 gallons per minute. The tunnel itself is kept clear of water by two motor-driven centrifugal pumps, each of which has a capacity of 100 gallons per minute. These pumps are situated in the tunnel at the foot of the Canadian gradient and discharge into a well at the Canadian entrance to the tunnel. A system of block signalling is used within the tunnel. The main contractors for the work were the American Westinghouse Company.

There are, of course, other American lines electrified on the single-phase system, but those dealt with are some of the most important. In America, as in this country, the system has met with considerable opposition, and many untrue statements have been made concerning it. A few years ago there were probably good grounds for complaint, for few new things are devoid of faults. Now, however, the system is well out of the experimental stage and is making rapid progress in many parts of the world.

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